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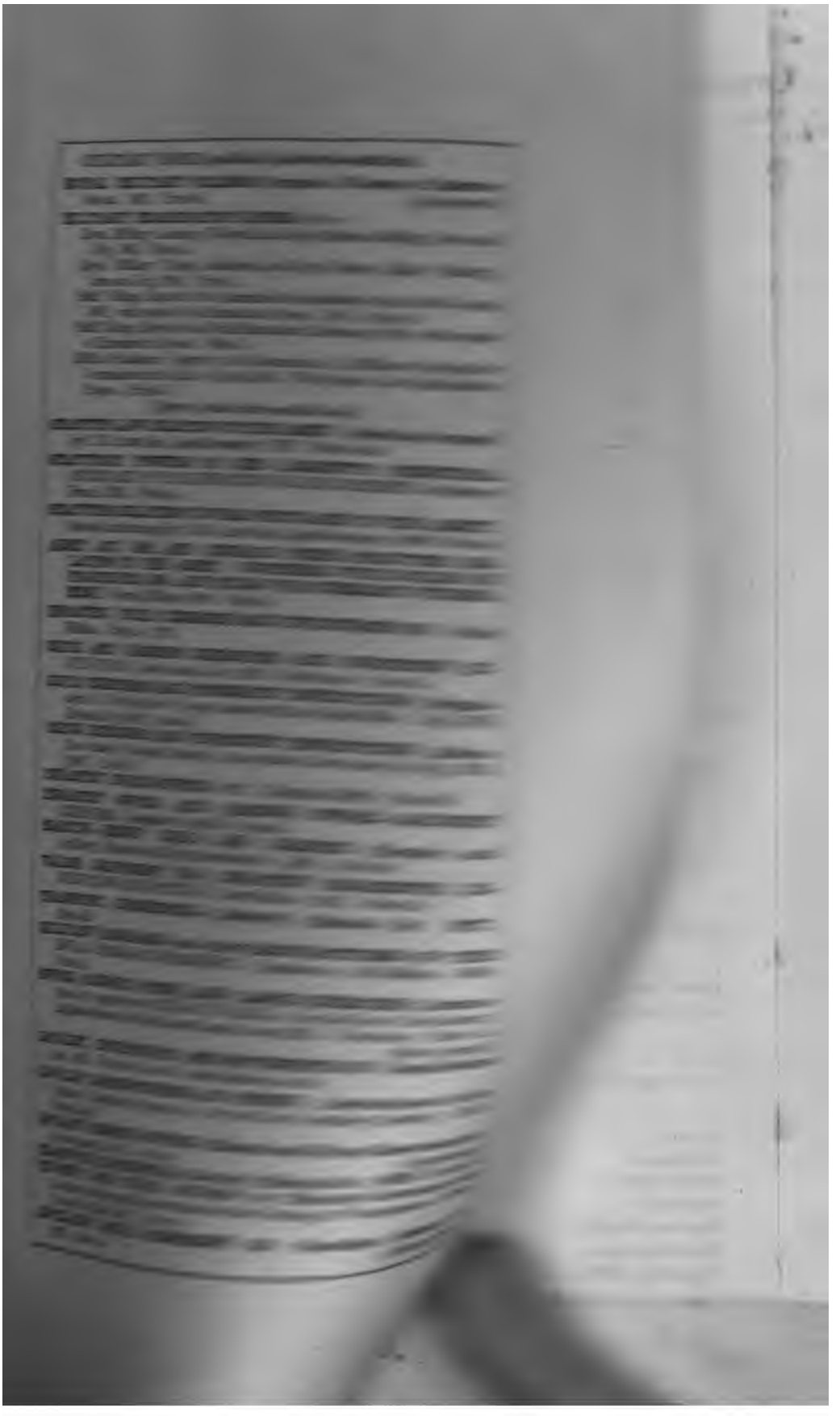

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PREFACE.

THE subjects in the first part as far as "the Rangefinder," inclusive, comprise the course at the Royal Military College.

The course at the Royal Military Academy includes the above, and in addition the chapter on the Pocket Sextant, and part of those on latitude, longitude, and determination of altitudes by the barometer.

The Theodolite, Trigonometrical surveying, Levelling, Road making, Horseback sketching, &c., belong to the Staff College course, in addition to the preceding parts of the book.

The author is indebted to the Rev. J. Twisden, M.A., Professor of Mathematics, Staff College, for the sections on determination of latitude and longitude and measurements of heights by the barometer.

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SECTION I.

INTRODUCTORY REMARKS.

Scales, Reducing and Enlarging Plans.

Surveying is the art of measuring the shape and size of the features on any portion of the earth's surface, and representing them on a reduced scale, so as to bring the whole under the eye at once. Its object, as applied to the art of war, is to explain by plan and by report the tactical capabilities of ground in anticipation of some military operation, or to illustrate operations which have taken place.

Such sketches generally comprise small portions of country represented on a large scale. They must be performed rapidly, as their value depends upon the information afforded by them being furnished in time to allow of its being acted on. Attention is paid to objects chiefly in proportion to their tactical importance, and therefore some objects are more strongly marked in these than in civil maps; gentle undulations of the ground may for instance be, in a military point of view, of paramount importance and therefore shown, whilst other features, such as slight fences, which would not give cover or impede movement, may be little noticed.

Again, the density of a wood rather than its exact area would first attract the notice of the military surveyor, though its extent would be sketched as accurately as time would permit. The present condition of the surface of the country, the extent to which woods and hedges interfere with the view or impede movement, in fact everything that affects the tactical aspect of the locality would be explained both by the plan and by writing. These sketches must convey no false information, nothing but what has been seen must be represented, and the tendency to sacrifice truth to effect must be guarded against.

The most valuable sketches of positions and lines of communication have often to be made under such circumstances that it would be impossible to attempt deliberate measurements, and it is especially in such work that the advantages of training and experience are evident, enabling correct conclusions to be drawn from slight indications; attention to be directed to that which is of real importance only; and a correct judgment as to what is required, to be quickly formed.

The practice of military surveying is in great measure a process of development of the perceptive faculties, and, whatever the natural aptitude for the subject may be, every officer may by proper training acquire some proficiency in this art, mere draughtsmanship being of minor importance in the present style of representing ground.

A very important habit engendered by military sketching is that of studying the forms of ground and thinking of their effect on military operations.

Any person can *survey* if time is unlimited, but it is only by practice that the combination of rapidity and accuracy required in military *sketching* can be attained.

"Map reading" or the ability of quickly grasping the correct meaning of a military plan, a faculty which every officer should possess, is not to be acquired without study. He who understands surveying is most likely to appreciate and make good use of the sketches produced by others.

Scales.

The construction of scales must be first mastered as entering into every branch of the subject.

The "scale" of a plan is the proportion the latter bears to the object which it represents. For instance, the scale of 1 inch to a foot implies that every object a foot long on the ground is represented on the plan by a length of an inch; this scale would also be described by the "representative fraction" $\frac{1}{12}$, because an inch is the twelfth of a foot. Similarly, a scale of 1 inch to a mile, which is that of the general maps of the Ordnance Survey of Great Britain, implies that every mile on the ground is represented by an inch on the plan, the representative fraction being, in this case, $\frac{1}{63360}$, there being 63,360 inches in a mile.

The numerator of the representative fraction is always unity.

Continental plans are usually drawn on scales, the denominators of the representative fractions of which are multiples of 10, as $\frac{1}{10000}$, $\frac{1}{25000}$, &c.

In this country, the inch being the unit of measure by which the eye is accustomed to judge distances on paper, it is usual to state the proportion of the plan to the ground as, for instance, "6 inches to a mile," an expression which conveys a clearer idea than the equivalent representative fraction, $\frac{1}{10560}$. The representative fraction, usually termed R.F., should, however, be also stated on the plan, to simplify comparison with maps in which different units of measure are used.

The scale on which plans are executed will depend on the amount of detail which it is desirable to show, and partly on the nature of the ground; when the detail of the country, for instance, is open, a smaller scale will often suffice than when it is close.

Positions, or sketches giving tactical information are usually drawn on the scale of 6 inches to a mile, though in a country containing little detail and large natural features, 3 or 4 inches to a mile would be sufficient.

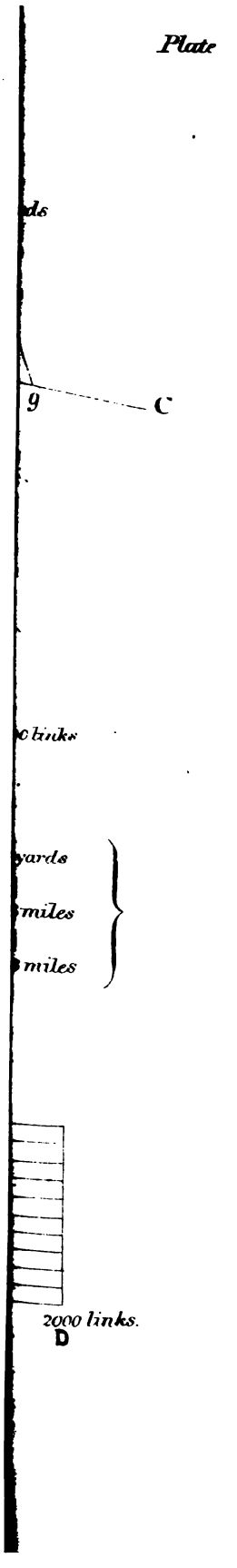
Routes and rivers sketched during instruction are drawn 3 to 6 inches to a mile; on service at 2 or even 1 inch to a mile.

Plans for strategical purposes showing large districts of country may be drawn at $1\frac{1}{2}$ inches to a mile, or less. The national surveys of the country are, as a rule, used for this purpose, the corrections necessary to show recent additions and alterations being made by the Staff.

The linear quantity which the scale is to show, whether miles, yards, or feet, is termed the "unit of measure."

The scale is usually drawn about 6 inches long.

For the construction of a scale, calculate how many tens, hundreds, or thousands of the unit of measure will occupy nearly 6 inches on paper. The object of assuming a decimal number of units is, to simplify the subsequent subdivision of the length by compasses or otherwise, into a whole number, without fractional remainder.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Ex. I. Suppose the scale required to be 15 inches to a mile, to show yards. Here the units of measure are yards.

We propose to make the scale about 5 inches long (or $\frac{1}{3}$ of a mile, 586 yards). Instead of this number assume a decimal number, say, 600.

Then by proportion—

Yards in a mile.		Yards in the scale.		Inches representing a mile.		Length of scale.
1760	:	600	::	15	:	5·11

The length of scale should be worked out to two places of decimals, a quantity measurable on a scale of inches.

Take 5·11 from the diagonal scale of inches. Divide this line AB into 6 equal parts of 100 yards each, called the primary divisions.

This is done by drawing another line AC at any angle with AB, and dividing it into any 6 equal parts, *b*, *c*, *d*, &c. Join B*g* and draw parallels to this from the points *f*, *e*, *d*, &c., intersecting AB in the required 6 equal parts. (Plate I.)

Subdivide the left division into 10 secondary parts each of 10 yards.

The zero of the scale should be placed as shown, and the primary and secondary divisions numbered outward from it.

It is evidently a more simple operation to divide this line 5·11 inches long into 6 equal parts, than to have assumed its length as exactly 5 inches, and divided it into 5·86 parts. There is no difficulty in taking the fractional quantity from the diagonal scale of inches.

If the diagonal scale of inches is not at hand, the required length may be taken from the artificial scale 30 of the Marquois scales, which shows inches and tenths; the second place of decimals may be taken by estimation.

Ex. II. To construct a scale of 8 inches to a mile, to read feet.

Here, the units of measurement being feet, of which a mile contains 5280, either 3000 or 4000 feet will produce a scale of convenient length—

Feet.		Feet.		Inches.
5280	:	3000	::	8 : 4·54 inches.

Lay off 4·54 inches on the paper and divide into three primary divisions of 1000 feet each, and subdivide the left division into secondary parts of 100 feet each.

Ex. III. Construct a scale of chains, 500 feet to an inch.

In scales of chains, links are usually taken as the unit of measure, 100 links = 66 feet; therefore 500 feet = 757·57 links.

An inch being = 757 links, 4000 links will produce a scale of convenient length—

Links.		Links.		Inch.
757	:	4000	::	1 : 5·28 inches, length of scale.

If the unit of measure is not named, that most convenient may be adopted; for example:—

Ex. IV. Construct a scale of 3 miles to 1·75 inches.

If we decide to show thousands of yards. Then as 3 miles or 5280 yards = 1·75 inches, we may assume 15,000 yards as a convenient number—

5280 : 15,000 :: 1·75 : 4·97 inches.

In this scale secondary divisions of 100 yards can be shown. Or if we decide to show miles and furlongs, 3 miles being = 1·75 inches, 9 miles is assumed for the scale—

$$3 : 9 :: 1{\cdot}75 : 5{\cdot}25 \text{ inches},$$

or the secondary divisions might show quarter miles. (Ex. IV, Pl. I.)

To find the representative fraction of a scale; make the given number of units of measure the denominator, and the number of inches which represents them the numerator. Reduce the fraction to one having its numerator unity.

Thus in Ex. I, 15 inches to a mile—

$$\frac{15 \text{ inches}}{1 \text{ mile}} \text{ or } \frac{15}{63{,}360} \text{ R.F. } \frac{1}{4224}.$$

In Ex. IV, 3 miles = 1·75 inches—

$$\frac{1{\cdot}75 \text{ inches}}{3 \text{ miles}} \text{ or } \frac{1{\cdot}75}{190{,}080} \text{ R.F. } \frac{1}{108{,}617{\cdot}1}.$$

Ex. V. To construct a scale when the R.F. is given. Let the R.F. be $\frac{1}{3000}$ and a scale of yards be required.

It is always convenient to consider the R.F. as stated in inches. 1 inch represents 3000 inches or 83·33 yards, so that 400 yards may be taken for the scale—

$$83{\cdot}33 : 400 :: 1 = 4{\cdot}8 \text{ inches}.$$

The primary divisions being hundreds, the secondary tens of yards.

Ex. VI. Construct scales for sketching on horseback.

The horse takes 110 strides cantering, and 290 walking a measured distance of 300 yards; and the rider rises in the saddle 90 times in trotting the same distance, R.F. $\frac{1}{25000}$.

Then 300 yards will be represented in plan by

$$\frac{300 \times 36}{25{,}000} = 0{\cdot}432 \text{ inch}.$$

As 110 cantering strides = 0·432 inch, 1500 may be taken for the scale—

$$110 : 1500 :: 0{\cdot}432 : 5{\cdot}89 \text{ inches}.$$

290 walking = 0·432 inch; assuming 3000 for the scale—

$$290 : 3000 :: 0{\cdot}432 : 4{\cdot}47 \text{ inches}.$$

90 trotting; assuming 1000 for the scale—

$$90 : 1000 :: 0{\cdot}432 : 4{\cdot}8 \text{ inches}.$$

Ex. VII. A sketch is found with no scale or R.F. marked on it. The distance between two objects represented in the sketch as 2·73 inches apart, is measured on the ground and found to be 765 yards. To construct a scale. The R.F. is $\frac{2{\cdot}73}{765 \times 36} = \frac{1}{10{,}087{\cdot}9}$.

As 2·73 inches represent 765 yards, assume 1500 yards for the scale—

$$765 : 1500 :: 2{\cdot}73 : 5{\cdot}35 \text{ inches}.$$

If called upon to make a sketch of ground when unprovided with instruments, the edge of a card may be marked with any equal parts

to represent hundreds of yards for use in the field. Its R.F. may be subsequently found.

Supposing the scale to measure 4·25 inches long, divided into 800 yards, its R.F. is $\frac{4{\cdot}25}{800 \times 36} = \frac{1}{6776{\cdot}5}$.

Comparative scales express the same proportion in different units of measure. For instance, a scale of yards might be prepared to examine a foreign plan whereon a scale of "mètres" is shown. Or a plan might have scales of yards, of feet, and of links given, comparative to each other, that is, having the same representative fraction.

Military operations are measured by the time taken in traversing distances. In mountainous country, where this time will vary greatly with the nature of the ground, a scale of hours will be a useful addition to a map.

The foregoing examples of plain scales are divided into primary and secondary divisions only.

If a third subdivision is required, the scale is constructed on the diagonal principle, thus—

Ex. VIII. Required a scale of chains to show 10 links—Scale 15 inches to a mile.

A mile contains 8000 links.

Assuming 3000 links—

8000 : 3000 : 15 : 5·62 inches.

Take AD = 5·62 inches and divide it into three parts of 1000 links each. (Plate I.)

Draw 10 lines parallel to AD at any equidistance, and raise perpendiculars at A, B, C, D. Subdivide the left division AB and EF into 10 parts of 100 links. Join these points of division diagonally, and number the scale as shown. Then if a distance of, say, 850 links is required, place the points of the compasses at × ×.

Ex. IX. Construct a scale of yards, feet, and inches, R.F. $\frac{1}{70}$.

An inch represents nearly two yards; assuming 8 yards for the scale. 8 yards = 288 inches. Therefore length of scale $\frac{288}{70} = 4{\cdot}11$ inches.

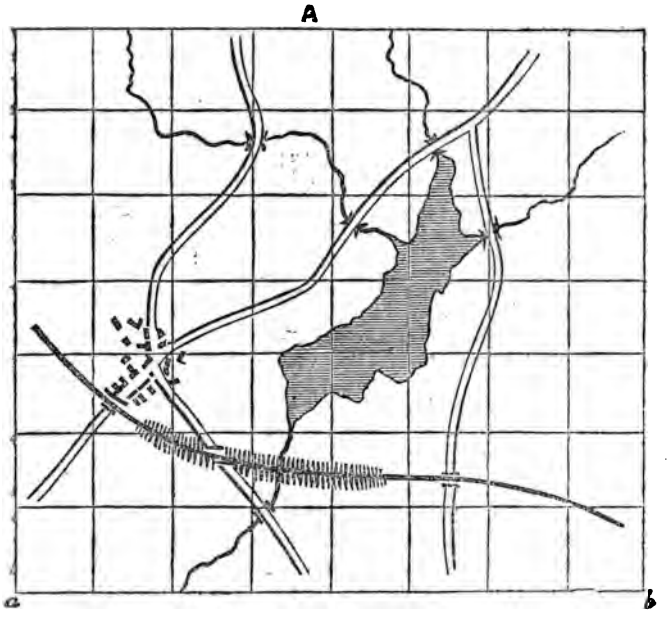
Here 12 lines are required parallel to the divided line. (Plate I.)

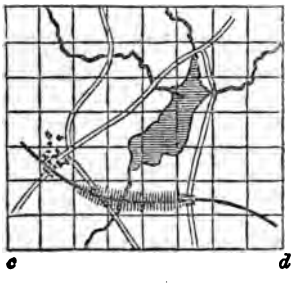
The sketching protractor usually has the scales of 6 and 8 inches to a mile engraved on it, equally suitable for sketching at scales which are multiples and measures of these numbers; *e.g.*:—

For sketching at 3 inches to a mile, multiply the measured distance by 2, and take it off the scale of 6 inches to a mile—or for 16 inches to a mile, divide the distance by 2 and use the scale of 8 inches to a mile.

Measurements in the field should be taken direct from the protractor without using compasses.

FIG. 1.





Copying, Reducing, and Enlarging Plans.

To make an enlargement or reduction of a plan, draw squares of any convenient size on the original. Prepare the paper for the copy with squares in the required proportion; the original can then be easily copied by eye, objects being placed in the copy in the same positions that they occupy relatively in the squares on the original.

Ex. I. It is required to reproduce at 4 inches to a mile a plan A, Fig. 1, the scale of which is 9 inches to a mile. The length of the plan A is 3·25 inches, therefore that of the copy will be 9 : 4 :: 3·25 : 1·44 inches. Divide each of them into the same number of equal parts, say 8. Raise perpendiculars at *a*, *b*, and *c*, *d*. On these set off as many of the same equal parts as may be required, and join the points forming the squares.

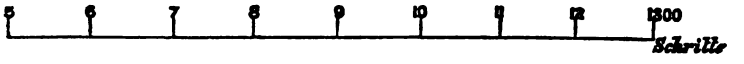
Ex. II. A plan with the R.F. $\frac{1}{2500}$ is to be copied at 6 inches to a mile.

The plan is 10 inches long.

The R.F. of 6 inches to a mile being $\frac{1}{10560}$, the length of the copy will be 10·560 : 25,000 : : 10 : 23·86 inches.

Ex. III. A Prussian plan, part of the scale of which is shown below, is to be reproduced at R.F. $\frac{1}{12000}$.

Fig. 2.



The schritt is 30 inches long. On examining the scale it is found that 1300 schritte or 39,000 inches measure 5·5 inches; its R.F. is therefore $\frac{1}{7091}$. Supposing the plan to be 12 inches long, the copy will be 12,000 : 7091 :: 12 : 7·09 inches; original and copy will then be divided into the same number of squares.

The size of the squares will depend on the scale and on the minuteness of the detail to be copied. It will be found that, as a rule, the squares from which an enlargement is made, or to which a reduction is made, should not have a less side than a quarter of an inch.

Plans which are to be simply copied without reduction or enlargement may be first traced on transparent paper, and then a piece of carbon paper being placed between the tracing and the copy, and both being firmly fastened down by drawing pins, the tracing may be transferred by following the lines with a pointed instrument, or the plan may be transferred direct, without a tracing, but there is some danger of damaging the original by the point.

Transparent muslin is useful for copying, as a drawing may be highly finished on it; it is tough, and will bear much handling. The drawing should be done on the glazed side, and washes of water color, when required, applied at the back, about twice as dark as they are intended to appear on the front.

The quickest and best way of copying when the original is on thin paper, is simply to pin the copy on it and to trace it through against a window pane.*

* If much copying has to be done, it is as well to prepare a sheet of glass with inch or half inch squares in ink, and lay this on the original, the copy being prepared with squares similar or in proportion to the required reduction or enlargement. This saves time, and prevents the defacement of plans.

In Survey Offices, reduction and enlargement of plans is performed by photo-

Examples.

1. Construct a scale of yards 4 inches to a mile.
2. „ a scale of miles 35 miles to 2·5 inches.
3. „ a scale of yards R.F. $\frac{1}{10000}$.
4. „ a scale of any convenient unit of measure, R.F. $\frac{1}{10}$.
5. „ a scales of 5 chains to an inch.
6. The distance between two points is known to be 1560 feet; on a plan these points are 13·7 inches apart. Construct a diagonal scale to read units of feet. Give the R.F.
7. You find that 232 of your paces are 200 yards, and that your horse when walking covers that distance in 185 steps, and when trotting in 123. Construct suitable scales. R.F. $\frac{1}{10403}$.
8. Construct comparative scales of links, mètres and feet. R.F. $\frac{1}{4000}$.
   (1 mètre = 39·37 inches, 100 links = 22 yards).
9. How many inches to a mile do the following fractions represent: $\frac{1}{1056}$, $\frac{1}{23749}$, $\frac{1}{127640}$?
10. Construct a diagonal scale to show thousandths of a foot, full size.
11. A map is 25 inches long, 24 broad; it represents an area of 40 acres; draw its scale of yards.
    (4840 square yards = 1 acre).
12. A plan, the R.F. of which is $\frac{1}{6000}$, is to be copied at R.F. $\frac{1}{18000}$. The original is prepared with one-inch squares. What will be the size of those prepared for the copy?
13. A plan is to be enlarged from the scale of "4 miles to an inch" to that of "3 inches to a mile." With what sized squares would you prepare the original and the copy?

The Conventional Signs.

It will be observed in the conventional signs used to represent objects in military sketches,* that vertical objects, such as trees, hedgerows, &c., are to be drawn perpendicularly, or parallel to the sides of the plan, with shadows falling horizontally to the right.

Water or marsh in lines parallel to the upper and lower margins of the plan. A few lines should be ruled in pencil to guide the hand in drawing these touches.

All printing should be done on lines ruled horizontally, except the directions of roads, and names of rivers, which should be printed along them. In the former the words "from" or "to" are used; "from" referring to towns on the left beyond the limit of the plan; "to" to those on the right.

Troops are drawn to scale according to their strength and formation, if the scale of the plan is large enough to admit of this being done.

In former conventional signs, the theory was adopted that light shone on objects from the left and upper sides, and therefore houses and roads (supposed to be raised) were given a dark and light edge. This theory is now abandoned with the object of simplifying the signs.

graphy, also by an instrument called a pantagraph; a description of these processes would be out of place in these pages.

* Revised by the War Office Committee, 1880.

At small scales houses are represented by a block, at large scales their form in plan is outlined. In either case they may be colored crimson lake whether built of stone or brick.

Electric Telegraph Line.—The dots are supposed to represent the posts in plan about 100 yards apart, at about which distance they are to be placed according to the scale of the drawing.

In double line of railway (distinguished from single line by sleepers drawn in black) these sleepers are to be drawn at the distance shown, whatever the scale of the plan may be. The words "single" or "double" are also to be written here and there along the line.

In drawing cuttings, embankments, and cliffs, a vertical touch is used, the stroke being perpendicular to, and thickest at, the top edge of the object.

Trees should be drawn as nearly as possible in proportion to those shown in the conventional signs, according to the scale.

SECTION II.

TERMS USED IN DESCRIBING HILLS.

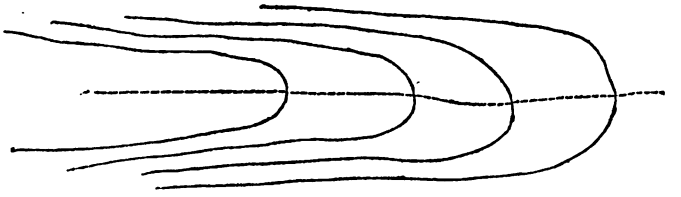
A few of the most usual terms are:—

Watershed. This term is accepted as synonymous with "water-parting," meaning the line which defines the highest part of any feature or chain of hills. The ridge of a roof illustrates the term. In the diagram (Plate IV), the road Xx nearly corresponds with the watershed of a feature.*

Watercourse. The line defining the lowest part of a valley whether occupied by a stream or not, as VV, RR, HH, in the same diagram.

When contours bend thus, the part of the ground represented by the dotted line must be either a watershed or a watercourse.

FIG. 3.

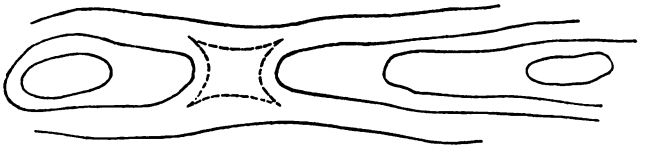


Col. The neck or saddle that connects adjacent heights.

The points D, L, M, S, Q (Plate IV) are cols.

In most foreign maps this feature is represented by a special conventional sign, an arrangement of impossible contours dotted thus:

FIG. 4.



Plateau. A flat surface on top of a hill as A (Plate IV), or in a more general sense as "the plateau before Sebastopol."

Table land. A high lying level district of country.

Basin. A level surrounded, or nearly surrounded by hills. The term is often used to express a large district drained by a river and its tributaries, as "the basin of the Ebro."

* This term has received the sanction of long use for the meaning here given, in which sense it has been employed by the best authorities. Much has been written as to its origin and correct meaning, but there is no question that confusion and mischief would result from any alteration of the long accepted usage. In the preface to Jackson's translation of "Levallée's Military Geography," 1840, will be found a clear account of its derivation, and of the reasons for then retaining the present acceptation.

Undulating. Ground consisting of alternate gentle elevations and depressions.

Ravine. A narrow valley with steep sides.

Spur. A prominent feature projecting from high ground.

Knoll, or *hillock.* A small eminence.

Underfeatures. The minor features which spring from main features.

The representation of hills.

Until lately, the authorised method of representing sloping ground. has been by shading produced by short strokes called hâchures, the thickness and number of which were regulated by a "scale of shade," according to the degree of slope.

Each stroke, or hâchure, being horizontal, the greatest slope at any place is a line intersecting the hâchures perpendicularly.

The "scale of shade" (Fig. 11) is the key to the expression of such a drawing as regards steepness of ground.

Various other styles of representing slopes by shade applied with brush or pen may be seen in former military sketches and plans; in the Ordnance Survey maps, hill features are represented by *vertical* hâchures.

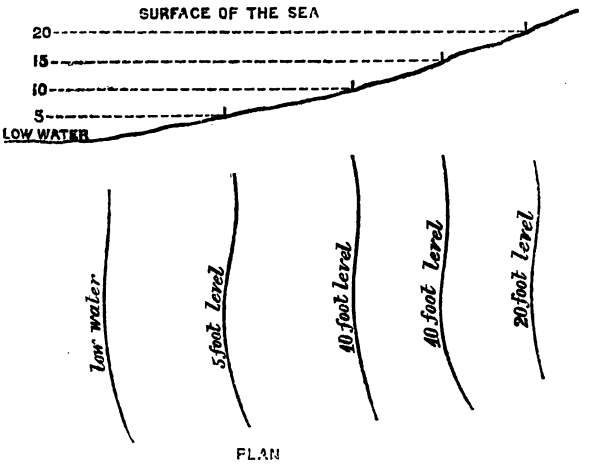
For rapid sketches, various systems of pen and pencil drawing have been advocated according to the fancy of the draughtsman and the fashion of the day, the object of all being, however, merely to produce an effect of shade.

Like other military sciences, the art of expressing ground has been much developed in late years, as shown by the maps accompanying the German official accounts of the actions in 1870–71, those of the battles of Gettysburg, &c., issued by the United States Secretary for War, and in fact all the best recent military plans in which hills are represented by contours.

It has been determined to abandon the system of indicating slopes and hill features by hâchures, and to adopt instead continuous contours supplemented by mezzotint shading, as presently described.

A contour is the line of *intersection of a hill by a horizontal plane.* In a survey, contours are placed at equal vertical intervals. For instance, the line defined by the edge of the sea on a shelving beach might be regarded as a contour, and others might be traced at, say, 5 feet intervals by marking the edge of the water each time its surface had fallen that quantity. These lines surveyed and drawn to scale would be a contour plan of the slope.

FIG. 5.

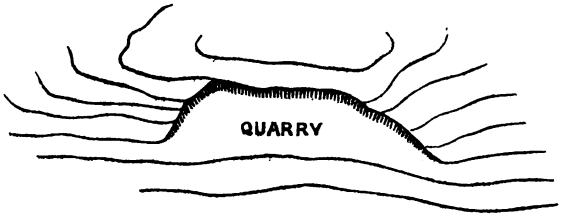


Besides the relative altitudes, the contours explain the shape and slope of every part, being close together in proportion to the steepness of the ground.

If a contour forms a ring which does not enclose any other, such as are shown at P, G, T, &c., Plate IV, it may be assumed that it is the top of a hill, as the only other form it could express would be the interior of an inverted cone, such as a crater.

If contours appear to touch one another, there must be a vertical cliff and the contours will re-appear where the cliff ends, as in Fig. 6.

FIG. 6.



THE SCALE OF HORIZONTAL EQUIVALENTS, OR SCALE OF SLOPES.

Two conditions must be known before the amount of slope in a contour plan can be recognised.

1st. The scale of the plan.

2nd. The "vertical interval" or difference of level between the contours.

The vertical interval will usually either be stated in the margin of the plan, or the contours will be numbered with their heights in feet above the sea or some assumed level.

Sometimes the "scale of slopes" or "scale of horizontal equivalents" (presently explained), will be given on the plan, by which the steepness of the ground may be judged.

There are two methods of describing a slope.

Firstly. That commonly used in construction of railways, fortifications, &c. *The gradient*, that is, the difference of level which occurs

in a certain horizontal distance, stated usually as a fraction, *e.g.*, one foot fall in 30 horizontally, or $\frac{1}{30}$. The gradients may be noticed marked alongside railways, thus, $\frac{1}{241}$ showing that there is a difference of level of 1 foot in 241 feet, or 1 yard in 241 yards.

Secondly. The slope may be expressed in *degrees* of elevation or depression above or below the horizontal plane. This method is most familiar to military men when reading maps or considering the tactical capabilities of ground.

A difference of level of 1 foot will occur in 57·3 feet on a slope of 1°* (stated as 1 in 57·3.)

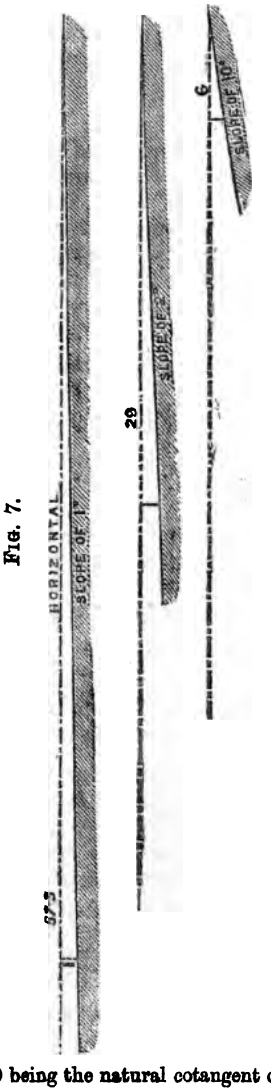


Fig. 7.

* 57·29 being the natural cotangent of 1°.

On a slope of 2° the same difference of level will evidently occur in half the horizontal distance (29 feet nearly) or $2° = 1$ in 29

$$3° = \frac{57{\cdot}3}{3} = 1 \text{ in } 19$$

$$10° = \frac{57{\cdot}3}{10} = 1 \text{ in } 6$$

and so on.

It is usual to employ the convenient number 60 instead of 57·3 for a rough approximation, and to consider—

1° as equivalent to 1 in 60
2° „ 1 „ 30
5° „ 1 „ 12, &c.

and conversely the degree of slope equivalent to the gradient—

1 in 20 is nearly 3°
1 „ 15 „ 4°
1 „ 6 „ 10°

Heights of hills, or the difference of level between any two points are always designated *in feet* in this country.

Distances usually *in yards* when measured on military plans. Therefore it will be useful to remember that the horizontal equivalent for *1 foot vertical, at 1° slope*, is *19·1 yards nearly* (57·3 feet).

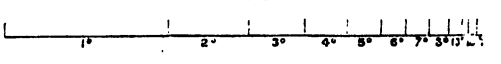
Hence can be found at once the horizontal equivalent for any given conditions. For instance, if the vertical interval be 10 feet, the horizontal equivalent for

1 foot at 1° being 19·1 yards
10 feet at 1° will be $19{\cdot}1 \times 10 = 191$ yards
10 feet at $2° = \frac{191}{2} = 95$ yards
„ „ $3° = \frac{191}{3} = 64$ yards, &c.*

These distances being drawn to the scale of the plan, constitute the "scale of slopes" or horizontal equivalents.

For instance, if the scale of the plan be 8 inches to a mile, the distances calculated as above will produce.

FIG. 8.



Horizontal equivalents for 10 feet, at 8 inches to a mile.

By measuring the distance between the contours on the plan by this scale, the steepness of the ground at any place may be known.

In order to avoid the necessity of constructing scales of horizontal equivalents suitable to different plan scales, a normal scale of horizontal equivalents has been adopted in this country, which is used, as a rule, for all sketches. The eye soon gets accustomed to recognise slopes as represented in plan by the normal scale.

It is constructed on the conditions of *horizontal equivalents for* 20 *feet vertical intervals drawn at the scale of* 6 *inches to a mile.*

Here horizontal equivalent for 20 feet at $1° = 19{\cdot}1 \times 20 = 382$ yards.

* This is only an approximation sufficiently close for sketching purposes. When

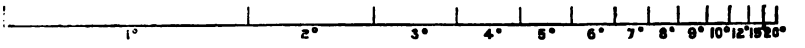
Horizontal equivalent for 20 feet at $2° = \frac{382}{2} = 191$ yards

$3° = \frac{382}{3} = 127$ yards

&c. &c.

Laid down at 6 inches to a mile, these distances produce—

Fig. 9.



Horizontal equivalents for 20 feet, 6 inches to mile.

similar to the scale given on the surveying protractor.

The adoption of this scale, to be used as a rule, does not preclude the employment of a scale of slopes based on different conditions when desirable; such as when the country is so flat that many features would lie between the normal contours, or so steep that they would be inconveniently crowded.

Points as *a*, *b* (Fig. 10), which are the *same distance* apart on plans drawn at *different scales*, evidently represent different actual distances, greater as the scale is smaller.

Fig. 10.

a·····*260, yards*·····*b* at 6 inches to a mile.
a·····*130, yards*·····*b* at 12 „ „
a·····*520, yards*·····*b* at 3 „ „

Hence it is seen that when the normal scale of horizontal equivalents is used for sketching at scales other than 6 inches to a mile, the *actual distances* in yards will be different to those which produced the normal scale (Fig. 9). At 12 inches to a mile, for instance, the horizontal equivalent for 2° instead of 191 yards will measure $95\frac{1}{2}$ yards; or at 3 inches to a mile will measure 382 yards.

The vertical interval between the contours will also differ in the same proportion, for in descending any slope the amount of rise or fall is in proportion to the distance, and if a difference of level of 20 feet occurs, as has been shown, in 191 yards on ground sloping 2°, only 10 feet will occur in 95 yards.

Hence the rule that when the normal scale of horizontal equivalents is used at other plan scales than 6 inches to a mile, the vertical interval between the contours will be in inverse ratio. The larger the scale the smaller the vertical interval.

the vertical interval is large, such as 100 feet, the difference between the approximate and the true horizontal equivalents would be apparent at steep slopes. The true equivalents may be obtained by multiplying the following distances by the vertical interval. For instance, the horizontal equivalent for 25 feet at 15° is 1·24 × 25 = 31·8 yards.

Horizontal Equivalents for 1 *Foot.*

1° = 19·10 yards.	11° = 1·71 yards.	21° = 0·868 yards.
2 = 9·54 „	12 = 1·57 „	22 = 0·825 „
3 = 6·36 „	13 = 1·44 „	23 = 0·785 „
4 = 4·77 „	14 = 1·34 „	24 = 0·748 „
5 = 3·81 „	15 = 1·24 „	25 = 0·715 „
6 = 3·17 „	16 = 1·16 „	26 = 0·683 „
7 = 2·71 „	17 = 1·09 „	27 = 0·654 „
8 = 2·37 „	18 = 1·03 „	28 = 0·627 „
9 = 2·10 „	19 = 0·968 „	29 = 0·601 „
10 = 1·89 „	20 = 0·916 „	30 = 0·577 „

For instance, the vertical interval which would produce the normal scale of horizontal equivalents similar to Fig. 9 would, if the plan were 9 inches to a mile, be—

9 : 6 :: 20 : 13·3 feet vertical interval;

if the plan scale were 4 inches to a mile—

4 : 6 :: 20 : 30 feet vertical interval.

The scale of slopes should always be given on sketches underneath the plan scale.

It will be observed that by the simple formula mentioned, (1° = 1 in 57·3 or 60 nearly) may be approximately solved most of the problems relating to heights and distances which occur in connection with military topography when the slope does not exceed about 20°—

(*a.*) It has been shown how when the vertical (or height) and the angle (or slope) are given, the distance (or horizontal equivalent) is found.

(*b.*) Given the distance and slope, to find the height. Distance 200 yards, slope 3°.

3° being $\frac{60}{3}$ nearly, = 1 in 20, therefore height of object is

$\frac{200}{20}$ = 10 yards, or 30 feet nearly.

(*c.*) Given the distance and height, to find the slope. Distance 180 yards, height 50 feet.

180 yards = 540 feet, therefore the gradient is 50 in 540, or 1 in 10·8, which is about $5\frac{1}{2}$°.

Examples.

1. State the vertical interval at which contours would be placed when using the normal scale of horizontal equivalents for sketching at 5 inches to a mile.
2. Construct a scale of horizontal equivalents for 50 feet contours on the scale of 4 inches to a mile.
3. Construct a scale of slopes suitable for the American War maps, of which the scale is 1000 feet to an inch, and contours at 4 feet vertical interval.
4. Show the horizontal equivalents for 1°, 2°, 3°, 5°, 7°, 10°, for a plan drawn at $\frac{1}{25000}$, on which contours are represented at 10 mètres vertical interval, 1 mètre = 39·37 inches.
5. From the top of a cliff 150 feet high, the angle of depression of a ship was observed 2°, how far off was she?
6. Wishing to find the height of a monument on a plain, a person paced 120 yards in a straight line from it. Here he observed the angle of elevation of its top $4\frac{1}{2}$°. How many feet was the top above the person's eye?
7. To find the height of an obelisk built on the summit of a slope a person measured 150 yards in a straight line from it, here he observed the angle of elevation of the top 10° and of the bottom 2°. What was it's height?
8. The top of a hill is marked 450 feet on a plan, the bottom 110 feet. The distance measured by the plan scale is 420 yards. What is the degree of slope of the hill-side?
9. What is the scale of a plan in which a slope of 20°, 100 feet high, measures 2·5 inches long?

SECTION III.

SHADING HILL FEATURES.

The effect to be produced is that of a transparent shade, dark in proportion to the steepness of the ground represented. Its object is to give body and expression to the contours, which are the outline of the hill-drawing performed in the field, and to explain and develop minor features of the ground which may lie between the contours. This style of shading being distinct from all line drawing, may be applied over the most crowded details without causing confusion, such as would be produced by hâchure shading.

The contours should be in crimson lake continuous lines of constant thickness, only strong enough to be visible through the deepest shade, but not too heavy.

A smooth hard surface should be under the drawing. Apply lead with a soft pencil about the parts where the shade is to be darkest. Rub this in firmly with a piece of chamois leather folded into a small pad, allowing the shade to be carried somewhat over the lighter portions also.

Apply more lead where the drawing is not dark enough, and again rub it in.

Lighten portions which are too dark with india-rubber; this will perhaps bring out the lights too vividly. With a clean part of the leather rub the edges firmly, which will have the effect of rounding and blending them, and of toning the light.

It is unnecessary to take the trouble of preserving the exact shape of crests of hills, &c., at first; these can be more easily brought to the required form afterwards by india-rubber.

To bring out any particular form sharply, cut a hole of the required shape in a piece of paper; hold this firmly over the place, and rub out out the light.

If it be required to shade a minute feature, use lead and the leather folded into a point.

The drawing should not be highly finished bit by bit, but the general effect of the whole should be given broadly at first, and the minor features gradually worked up.

Any rough granular appearance in the shade may be flattened and highly finished by rubbing firmly with clean leather. Care should be taken finally to clean all shade from the margins and level portions.

Should the pencil be so hard as to leave marks which cannot be smoothed out with the leather, scrape lead from it on to the drawing where required, or on to a spare piece of paper, whence it may be transferred by the leather.

The shade should be so firmly applied as to bear handling, but may be fixed indelibly by floating a wash of isinglass or thin gum-water over it.

Colour should be applied to roads and woods when required, after the shading is finished.

Low-lying levels should be kept down by a very light shade, whilst the tops of hills should be left void of shade to distinguish them. Watersheds made lighter than watercourses.

The depth of shade must be regulated by the authorised scale of shade, the degree of slope being ascertained by measuring the distance between the contours with the scale of horizontal equivalents suitable to the conditions of the plan.

The deepest shade which can be produced without opacity represents 35°. The shade is not to be increased for steeper ground, which will be sufficiently shown by the proximity of the contours.

THE EXAMPLES OF HILL SHADING IN MEZZOTINT.

In copying these examples the contours should be drawn in crimson lake, the streams and water in Prussian blue.

In the Ist example the upper two are for practice in producing a perfectly even, smooth tint. The high finish is obtained by rubbing with a clean part of the leather, which will remove any unevenness or granular appearance.

In producing each piece of shade it will be in the centre of the portion of paper to which lead is applied; the excess portion is afterwards rubbed out with pencil eraser, a stout piece of paper or card being firmly held on the drawing so as to protect that which is to remain.

In the two centre examples the gradations are obtained by adding lead for the darker parts after the flat shade has been produced as above; and by removing lead from the lighter parts with pencil eraser, afterwards blending them by rubbing with the leather.

The left lower example is produced as above, placing the darkest shade near the centre, and then erasing the high light; the right lower example is produced in the same manner as the left, but the high light is afterwards toned and softened by the leather.

3rd example. Observe that the contours are placed according to scales of horizontal equivalents different to the normal scale on the protractor.

4th and 5th examples. The vertical intervals between the contours are such as produce a scale of horizontal equivalents similar to the normal scale, by which, therefore, the degree of slope at any part may be gauged.

6th example. A scale of horizontal equivalents should be prepared suitable to the conditions given, R.F. $\frac{1}{2500}$, 15 feet contours. By this scale the slopes will be gauged.

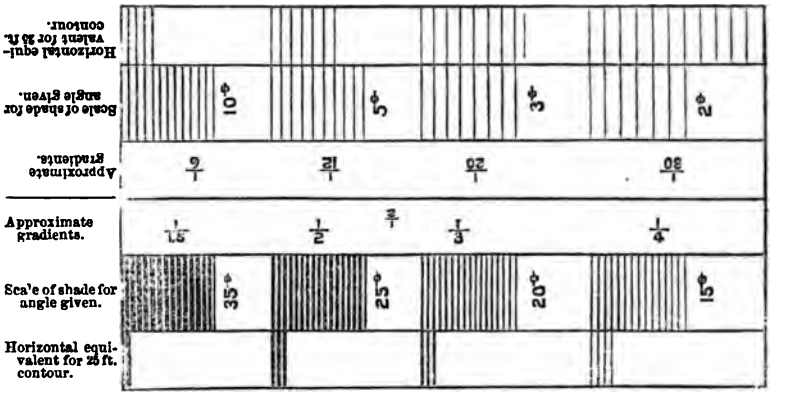
HÂCHURE SHADING.

Although hill shading by hâchures has been abandoned for general military purposes, it is thought desirable to give the following explanation of the process.

The following scale of shade defines the strength and numbers of the hâchures by which certain slopes are to be represented at all scales, when this style of hill shading is employed.

FIG. 11.

From 35° to 45° the lines may increase in thickness, according to the draughtsman's skill, their number being constant.

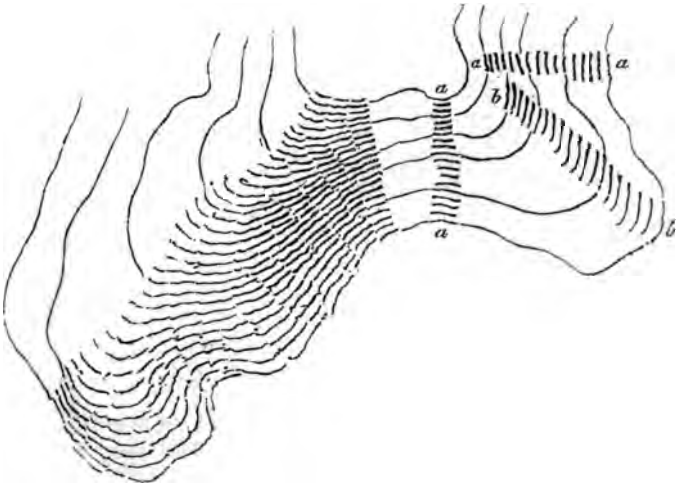


A fine but not very stiff steel pen, such as Gillotts' 303, should be used.

The horizontal equivalents on the above are for 25 feet vertical, constructed at 6 inches to a mile, and are therefore wider than the present authorised normal scale of horizontal equivalents (for 20 feet at 6 inches to a mile).

To shade a contoured plan, apply the scale of horizontal equivalents on the outer edge of the scale of shade, to the space between any two contours, perpendicular to them, so as to find the degree of slope nearly, and draw a few touches of the proper thickness as if in continuation of the lines given, *aa*. (Fig. 12).

FIG. 12.



The centre blank portion of the card may be cut out, so as to allow of the shade being conveniently applied to the drawing.

Mark off a few hâchures here and there in this manner, wherever

the distance between the contours varies, so as to obtain a key to the tone of shade of the whole. Hills should be shaded from the top downwards, and the different degrees of shade expressing the varying steepness blended in a natural manner.

The axis of each row of hâchures must be at right angles to the contours as *aa*, never as *bb*.

Each touch is to partake of the same amount of curve as the contours between which it lies.

The shading must not be carried round a hill in bands between two contours at a time; this would mar the effect of roundness of forms produced by blending the shades.

In drawing the darker shades the pen must be held rather flat, and with both nibs resting equally on the paper.

The position of the sketch is to be shifted as required, so that the hâchures may be drawn towards the draughtsman.

Each touch is to be of the same thickness throughout, and to be drawn quite firmly. In the darker shades the touch is to be shorter than in the lighter, which may be drawn slightly broken, so as to avoid the effect of continuous lines.

The length of the touches should be varied a little, so as to break up the rows and prevent the eye from being attracted to the spaces between.

The beginner should draw very slowly, each touch being executed with care and deliberation; freedom of execution will follow with practice.

The hâchures to be drawn from right to left, so that the point of the pen may not hide the adjacent hâchure, and that the next may be placed at the desired distance from it.

In order to distinguish the contours through the shading, they are to be chain dotted or drawn in colour, but in such a manner as not to impair the effect of the shading by being too prominent.

The maximum shade given in the scale is for 35°; natural slopes steeper than this are rarely met with except in rocky ground; if they exist in the drawing the draughtsman should express them by increasing the strength, but not the number of the hâchures.

Beyond 45° ground is nearly impracticable, and may be represented by vertical or broken touches.

Drawing from Models.

The model must be viewed from a point vertically above it (not obliquely); thus steep slopes will be seen as occupying only their proper space, or the base on which they stand.

Begin by drawing the rivers, roads, sea coast, and whatever detail is shown on the model, leaving the contours till the last.

These details should be copied by measurement either with compasses or a slip of paper. The most important roads and largest streams to be copied first in the following manner.

Measure the horizontal distance between two well marked points on the model, such as cross roads, or capes, as wide apart as possible within the defined limits. Mark these on the drawing. Take the distance of a third well marked object on the model from the two first, and describe arcs on the drawing from the corresponding points, their intersection will place the object. Continue this process until a sufficient number of points have been accurately placed to enable

the intermediate details to be sketched without further measurement.

As soon as the detail is drawn, it should be inked in, in accordance with the conventional signs; so that the pencilling of the contour sketching which follows, may be rubbed out and altered without obliterating it.

If contours are marked on the model, draw those indicating the hill tops first, then the cols, next mark on the watercourses and watersheds the extreme inward and outward bends of the contours. The watercourses should be faintly indicated in blue chalk (whether there be water in them or no) before sketching the contours.

In sketching models on which no contours are shown, it is usual merely to represent the ground by any convenient number of contours vertically equidistant, usually eight or four, as may best suit the ground. First decide which is the highest part of the model, and draw the contour representing it. Then the sea coast or lowest level. Next judge by eye the position of the contour which would intersect the ground at half its vertical height, and continue thus to subdivide the ground into the required number of equidistant planes.

SECTIONS.

A section represents the intersection of a hill by a vertical plane.

To draw a section on KL, Plate IV. Lay a straight edged piece of paper along the section line in the plan and mark on it the exact points in which the contours cut this line. Number these points so as to identify the contours, calling the lowest contour 0; care must be taken that each time the same contour cuts the section line it is figured similarly.

Take a number of equidistant parallel lines (Fig. 13) to represent the planes of the contours; figure them 0, 1, 2, 3, &c., from the lowest upwards. Transfer the points from the edge of the piece of paper to the lowest of these lines, and raise perpendiculars to meet the corresponding contour planes. Join the heights so found. (Fig. 13).

The vertical scale is usually exaggerated purposely, in order to show more strikingly the changes of slope which in a true section would be barely perceptible. In such a case the section does not give a true picture of the height of the hill. The exaggeration or proportion of the vertical to the horizontal scale should be stated underneath the section, as " heights to distances 5 to 1," &c.

Supposing a section on PN (Plate IV) required.

Scale of diagram 12 inches to a mile, vertical interval 15 feet. Heights to distances as 4 to 1.

Draw a series of horizontal lines (Fig. 14) to represent the contour planes at equidistances corresponding to the conditions. That is, 15×4 (exaggeration) $= 60$ feet.

Take, say, 10 contours, then the distance between the top and bottom line will be 600 feet. The scale being 12 inches to a mile (5280 feet)—

$$5280 : 600 :: 12 : 1{\cdot}36 \text{ inches apart.}$$

Subdivide this distance into 10 equidistant contour planes.

When the contours marked on the plan are taken from the sea level, all the sections may be drawn to show the absolute vertical development above the sea, which would be the lowest of the contour planes.

FIG. 13.

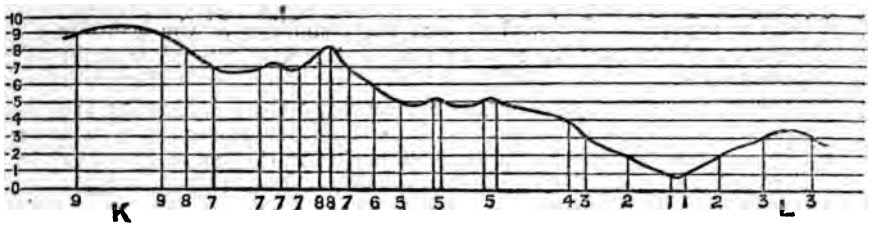
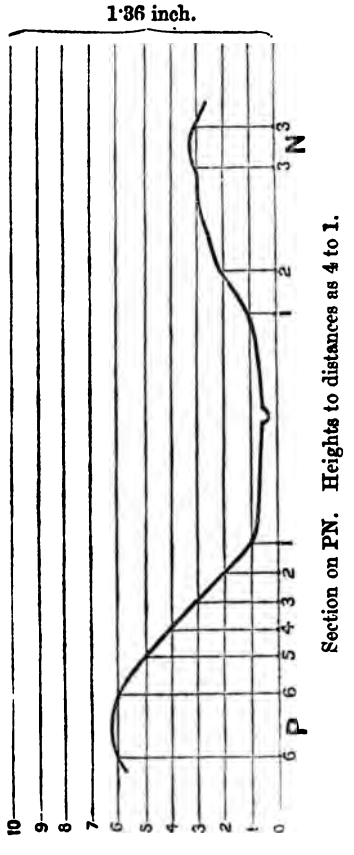
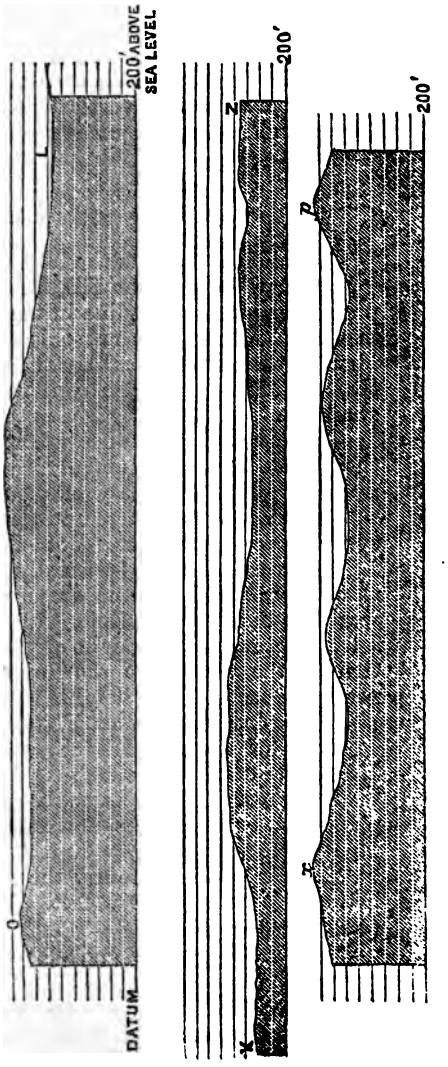


FIG. 14.



Section on PN. Heights to distances as 4 to 1.

FIG. 15.



But in connection with inland plans, it is more usual merely to assume a " datum level " below the lowest part of the ground shown in the plan, and to draw all the sections as based on this, so that the relative heights of the ground may be compared. Thus, supposing that the lowest contour in (Plate IV) were numbered 215 feet, the sections (Fig. 15) might be drawn with reference to a datum 200, as shown.

SECTION IV.

MAKING USE OF PLANS ON THE GROUND.

The first thing necessary is to study the scale and to impress thoroughly on the mind the space in plan which such distances as 100 yards, ½ mile, and a mile will occupy. From the habit of regarding chiefly large scale sketches, officers are usually at fault in the distance at which they expect to find objects which are shown on the one inch Ordnance Survey.

The map should, if possible, be first taken to some commanding spot which can be identified thereon. Here it will be spread out and placed so that its position shall correspond with that of the country.

This may be done in two ways. Firstly, if any other distant conspicuous point can be identified, a straight edged rule is laid with its edge connecting the two points (the observer's place and the distant point on the map). The map is now turned round until the edge of the ruler, so placed, is aimed at the distant point in the country.

Secondly, by means of a common pocket compass. All Ordnance Survey maps have their side margins true north and south. Supposing the observer to be in the south of England, his compass will not point to the true north, but about 18° west of it,* so that a magnetic meridian must be drawn by means of a protractor 18 degrees to the left of one of the side edges of the map, to correspond with the magnetic needle.

The compass is laid immediately over this line, and the whole map turned until the needle corresponds with it. Care must be taken that there is no mass of iron close by.

The plan being arranged by either of these methods and weighted down to prevent it from being disturbed, the observer may aim the ruler towards distant points, pivotting it always on the spot in the plan that represents his place. If he is a good judge of long distances, he will now have no difficulty in recognising places and their names in the map, and he should, if necessary, examine them with field glasses and impress their appearance on his memory.

One of the difficulties in making use of existing maps of a strange country is, that few of them are corrected up to date, and time may be lost in endeavouring to find roads that have ceased to exist, or in searching the map in vain for important buildings, railways, &c., which ought to be shown. Mere tracks or field paths sometimes appear on the maps as roads.

The observer's place may be found in the map at any time that two distant points which are shown thereon can be recognised in the country. He should "set" the map by the compass as described, and aim the ruler at the distant points, its edge passing through the corresponding points on the map; the intersection of lines drawn towards himself fixes his position.

If he judges that he is on a certain road, and wishes to find his exact place on it, he will notice some distant public building, peculiar hill, or other conspicuous object, which he can also identify on the

* Further details on this subject page 44.

map. "Set" the map by the compass, adjust the ruler in such a manner that its edge may coincide with the object on the map whilst directed on the corresponding distant object. The edge of the ruler will pass through the road at the observer's place.

In following a road and making one's way about a strange country, it is generally sufficient to hold the map in the hand, corresponding in position with the ground, in order to recognise near objects.

A rough approximation to the direction of the true meridian for finding one's way by the aid of a map, is to hold a watch with its face level, and with the hour hand directed towards the sun, then an imaginary line drawn from the centre of the dial bisecting the lesser of the two spaces or angles between the hour hand and the figure XII will be the direction of the meridian within about 20°. This simple expedient is useful on horseback, as it enables one to hold the map with its sides nearly north and south without dismounting.

Measurement of distance.

In military sketching the distances are usually merely measured by pacing or by counting the paces of a horse. After a little practice the error in distance thus measured will not exceed about 3 per cent.

The student should test his pacing over a measured distance of one or two hundred yards. Most persons find no difficulty in pacing yards if they walk quickly, though their natural pace when walking slowly may be only 30 or 32 inches.

The pacing should be tested not only on smooth hard ground, but also through heath and ploughed land, which produces a tendency to pace short. The length of the pace must be sensibly reduced in pacing down steep slopes, and increased in pacing up them.

A fruitful source of error in sketching is to lose count of the number of hundreds of yards that have been paced. Some system of recording these should be adopted, such as closing a finger for each hundred, or making a score on the sketch. The former is the best, as it does not entail halting.

A mounted officer should know the length of his horse's paces at the walk and trot, by trial over a measured distance. In trotting, the number of times the rider rises in the saddle should be counted. The paces of a horse are quite as constant in length as those of a man, the average length at the walk is 33 inches. A young horse will pace 39 or 40 inches.

A very accurate measurement of distance on a road may be obtained by counting the revolutions of the wheel of a vehicle and multiplying this number by its circumference, which can be measured with a tape; a white mark should be fastened to one of the spokes by means of which the revolutions can be counted.

Distances can be roughly estimated by the time taken in traversing them.

The rate at which sound travels being known (nearly 400 yards a second), distances might be estimated thereby, but this method is of little practical use to the military surveyor.

Most important of all is the correct estimation of distances by eye; without this faculty an officer will never be an expert military surveyor. It is by this means that the most rapid and urgent sketching is chiefly executed.

Small distances up to 60 or 80 yards should as a rule be always estimated in military sketching.

In traversing, the number of paces should be counted continuously from one station to another. The object of this is, that if an error should happen to be made in laying down any distance in the sketch, such error may not be carried on (as would be the case were the counting recommenced at 0 after halting to sketch detail). The counting begins afresh only at the change of direction.

Measurement of distance by chain, being used in regular surveying is described elsewhere.

TRIANGULATION.

When there is time for deliberate measurement, it is usual to commence a sketch by determining the position of a number of conspicuous objects, either natural or artificial, with as much care and exactitude as circumstances will permit, by an operation termed triangulation.

These objects, or stations, serve as starting places from which to commence the survey of the details of the ground, and afford the means of checking the accuracy of the work whilst in progress.

To illustrate the idea of triangulation without reference to any of the instruments employed in the process.

Supposing that a sheet of paper can be laid down at a place whence a commanding view of the surrounding country can be obtained, and straight lines drawn on it from a point A (Fig. 16) (assumed to correspond with this place on the ground) towards such objects as church spires, sign posts, chimneys B, C, D, E; that it is then taken to one of these places, B, and placed so that BA is directed towards A, and lines again drawn in the direction of the same objects from the point B taken in the line AB. The intersection of these lines with those first drawn will take place at points on the paper, bearing the same relation to each other as do the objects in the country.

Now all that is required is to know the distance between A and B; this distance is termed the base.

In selecting the position of the base for a survey, the following general rules should be observed as far as practicable:—

(1.) It should occupy a central position.
(2.) The slopes over which it passes should not be very steep.
(3.) A good view of the country should be obtainable from both ends.
(4.) The longer it is the better, subject to such limitations as are imposed by the range of sight, and the spherical form of the earth which generally preclude a greater length than 7 or 8 miles in extensive surveys. For most military sketches a base of from 600 to 1200 yards is sufficient.

The sides of the first series of triangles may be taken as fresh bases upon which other secondary triangles may be formed to determine the position of more distant stations, and the triangulation is thus extended until it embraces the entire district. The accuracy of the triangulation depends chiefly on the nature of the angles at the vertices or stations. This angle should be neither very acute nor obtuse, generally between 60° and 120°. The intersection at 90°

would give the most accurate determination. Hence the rules in selecting stations to be fixed from a base are—

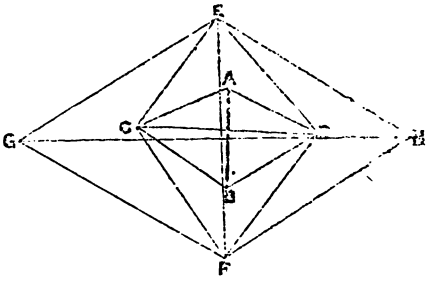
1. The station should not be much more distant than the length of the base.
2. It should not lie much outside a perpendicular to the base at either extremity.

In arranging a triangulation, the direction of stations unsuitably situated as regards the ends of the base, may be observed with the view of subsequently intersecting them from a more favourably situated station. For instance, the direction of H, Fig. 17, might be laid down from B (although it lies behind the base) with the view of subsequently intersecting it from C.

The number of stations chiefly depends on the scale of the survey. Stations are convenient about 2 or 3 inches apart on the plan, so that if the scale were to be, say, 12 inches to a mile, the stations might be selected as near to each other as 500 or 600 yards, whilst if the scale were to be 3 inches to a mile, they should be as far apart as 1200 yards or so.

The nature of the country may preclude the possibility of finding a good base, of length proportioned to the extent of the survey. For instance, in a mountain region, where tolerably level ground can only be found in the valleys; in these cases the size of the triangles and length of the bases may be rapidly extended without admitting any acute intersection, as follows:—

FIG. 16.



Supposing AB to be the only suitable ground on which a base can be measured: from these points good intersections of C and D on adjacent heights can be obtained. Taking the line CD as a fresh base, E and F may be thence determined. Then G and H and so on, increasing the length of successive bases.

In setting up marks on the ground to serve as stations, it is necessary to consider the appearance they will present from the point of observation.

If the station is on a hill top, and will be seen against the sky, a dark object, such as a disc or a bundle of heather fastened on a pole, will show distinctly. If one of the points of observation is so placed that the mark will have a dark background when seen from it, a white flag will have to be fastened to the pole in addition.

The accuracy of a station may be verified by intersecting it from a third point; for instance E (Fig. 16), might be intersected from A, and

judged to be correct if the line passed through the point at which the lines CE, DE previously placed it.

The measurement of the base should be performed with great care, as the accuracy of the whole sketch is dependent on it. If time admits the base should be paced twice.

The preceding remarks only apply to small military sketches in which the earth is regarded as a plane and not as a sphere.

In regular surveys, triangulation is an operation carried out with an elaboration which it would be foreign to the present subject to describe.

The Plane Table.

The processes of surveying with the plane table are extremely simple; the direction of objects is at once laid down without a protractor, without any angular measurement, and with greater certainty than could be obtained by the use of observing instruments. Its chief disadvantage as compared with the prismatic compass is its bulk, which detracts from its convenience as an apparatus for use on service.

It consists of a board (on which is spread the sketch sheet) attached to a tripod stand by a bolt. The board or plane table may be revolved to any position, and then fixed by tightening the nut or clamping screw attached to the bolt underneath it. A box containing a magnetic needle, usually placed underneath the board, may be pulled out far enough to show the north end of the needle, or may be withdrawn altogether if required.

The direction of objects is drawn by means of a ruler provided with sights, one of which has a slit to which the eye is applied; the other has a hair which is brought to bear on the distant object.

A needle set in a wooden handle is usually driven into the sketch at the point corresponding to the observer's place, and the edge of the ruler is pivotted against this in observing a direction. In rough work, this needle may be dispensed with, and any straight-edged piece of wood may be used instead of the sighted ruler.

To detach the board from the tripod, loosen the clamping screw as far as it will go; raise the bolt with one hand from underneath, whilst with the other the board is moved sideways until it can be lifted off.

In setting up the plane table, it must be levelled by the position of the legs; it is generally sufficient to effect this by eye, but if requisite the levelness may be tested by placing a bullet on the board. The legs should be pressed firmly into the ground, so that the position of the sketch may not be liable to alteration.

The employment of the plane table in triangulation will illustrate its use. Having selected and measured a base AB (Fig. 17), the table is placed at A and levelled. The clamping screw is loosened, and the compass box pulled out far enough to show the end of the magnetic needle. The board is now revolved until the magnetic needle points to the index or mark inside the box, then firmly clamped.

It is next necessary to decide in what part of the paper A shall be placed, so that the whole of the sketch may lie within the sheet; the needle is driven into the point selected.

The edge of the ruler is placed against the needle, and the sights aimed at B, C, D, E, &c., in succession, a fine line being drawn towards each of them. The ruler lastly directed again on B; if the

edge now corresponds with the line AB, it proves that the original position of the board has remained unaltered.

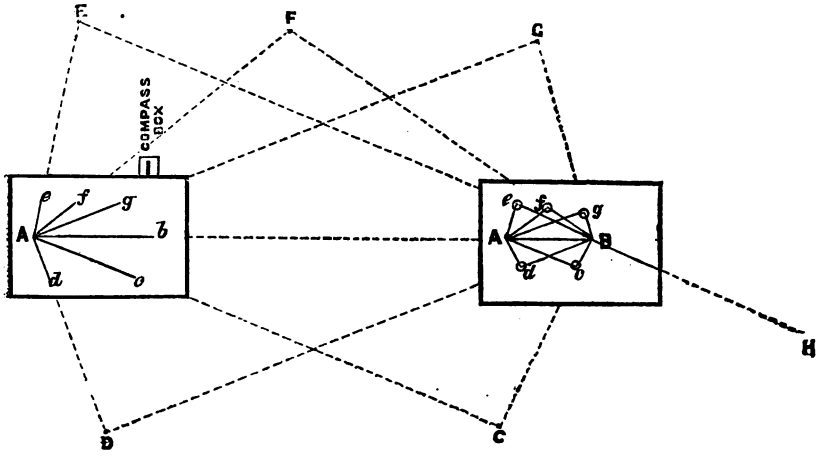
The length of AB, laid off to scale, fixes B in the sketch. The compass box is now pushed in until it may be again required.

The table is carried to B, the needle driven into the corresponding point in the sketch, the board unclamped, and the edge of the ruler adjusted accurately to the line AB. The board is now revolved until the sights are directed on A, then clamped.

The process is then repeated of pivotting the ruler against the needle and directing it on C, D, E, &c. The points where the edge intersects the relative lines previously drawn from A towards these stations, are surrounded by a small circle thus ⊙, marking their position.

Lastly, the ruler is aimed at A to prove that the board has not

FIG. 17.



moved. The plane table may then be taken to the stations thus fixed and fresh points observed from them, care being taken that the intersection at the distant point is not too acute. The direction of these lines is taken with reference to visible stations already determined, by means of which the board is "set."

In placing the plane table at a station on the ground, it is, strictly speaking, not the centre of the board, but *the station on the sketch* that should be vertically over the spot. This exactitude could, however, seldom produce an appreciable difference.

Finding the Place by Interpolation.

Having determined stations by triangulation, as described, the surveyor may, by reference to them, find the point on his survey which corresponds to his position on the ground, and may thus determine fresh stations, or commence surveying the details at any convenient place, such as a cross road where he may happen to be. The

most convenient way of finding the place is with the aid of the magnetic needle; in this case only two known stations need be visible. Pull out the compass box and revolve the board until the magnetic needle points to the index, as it did when the triangulation was commenced. The position of the board is now similar, or parallel to, its original position.*

Supposing E and F (Fig. 18, I) to be visible. Drive the needle into one of these, *e* in the sketch, pivot the ruler on this, aim it at E in the distance, and draw a line towards oneself. Repeat the process with regard to F; the edge of the ruler will intersect the first line in or near the required point *g*.

Owing to magnetic inaccuracy there may be some slight error in the place so found, the magnetic needle not lying exactly parallel to its original position. The accuracy may be verified, if any other stations are visible, by aiming the ruler at them.

If lines drawn from them, instead of intersecting the same point, form a figure about it in the sketch, it shows that the board is not "set" truly, and it must be revolved until it will stand the test. The direction and amount of alteration may be inferred from the aberration of the test lines. Or should the error be very small, it may be sufficient to take the centre of the figure formed by the lines.

Finding the Place without the Magnetic Needle.

(*a.*) At least three stations must be visible as a rule, in order to interpolate the place without a compass. It may be possible to place oneself in line with two, as CD (Fig. 18, II), and at the same time with other two, EF, on the ground; the corresponding lines drawn in the sketch determine *x*.

(*b.*) Supposing A, B, and C to be visible, the observer being somewhere below C. By moving until he is in the prolongation of the line AC, he can "set" his sketch by the ruler laid on the line *ca* (Fig. 18, III). Now drive the needle into *b* and, pivoting the ruler on it, aim at B, its edge will intersect *cx* in the required point *d*.

(*c.*) Or, if somewhere between A and C, he may place himself exactly *on* that line as described below, "set" the sketch by laying the ruler on the line *ac* (Fig. 18, IV), and turning the board until the sights are directed on A or C; pivot the ruler on *b* and aim at B, its edge will intersect *ac* in the required point *h*. The surveyor may place himself on the line *between* two distant points by observing them alternately from opposite ends of the ruler laid on the board, and shifting the position of the whole table to the right or left, until the sights are found to bear on the objects when viewed from either end.

(*d.*) A piece of transparent paper may be fastened on the board by pins, and lines *a*, *b*, *c* drawn upon it from any point *x* in the direction of three visible stations A, B, C. This is now taken up, laid on the plan, and shifted about, until each of the lines passes through its corresponding station. Then the point *x* may be pricked through on to the sketch (Fig. 19).

This process is known as "finding the place by adjustment."

* There is no recognised English equivalent for "orienter," the term used by the French to express placing the survey in a position corresponding with the ground. The process, whether performed with or without the magnetic needle will be termed here "setting" the sketch.

FIG. 18.

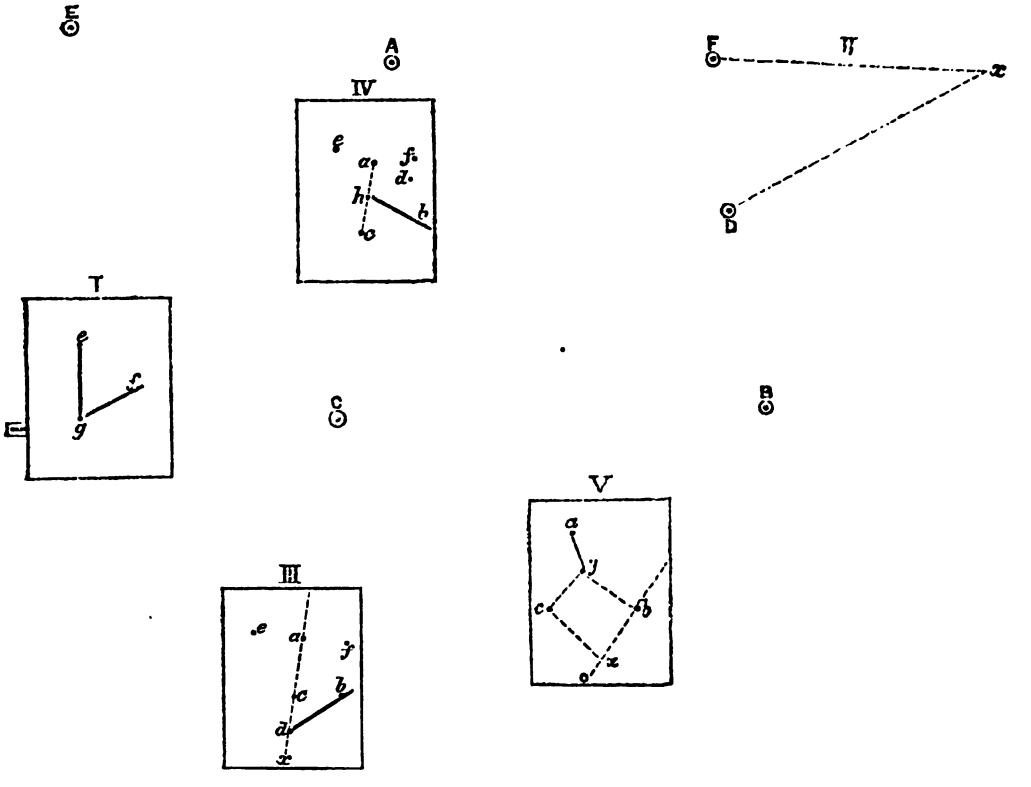
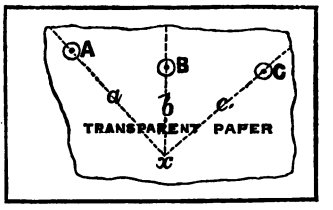


FIG. 19.



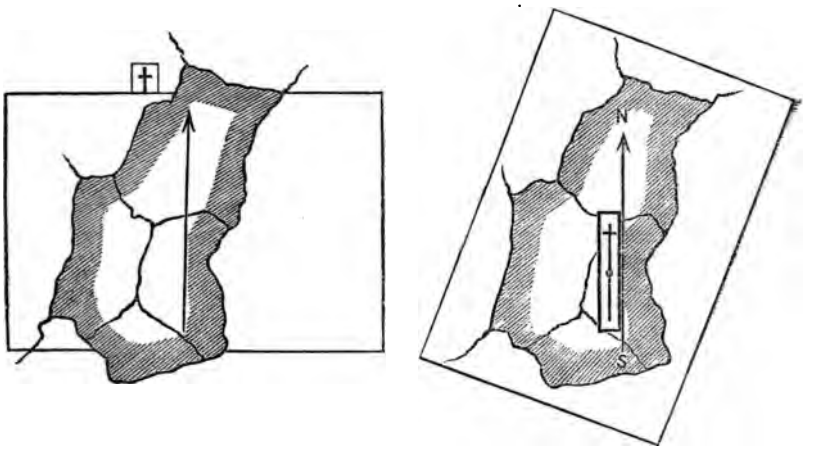
(*e.*) Or from three visible stations C, B, A (Fig, 18, V), represented on the sketch by *c*, *b*, *a*, the place may be found thus :—

By the ruler align *cb* on B, and from *c* draw a line *c*, *y* towards A. Align *bc* on C, and draw another line towards A intersecting the first at *y*. Adjust the ruler to *ya* and revolve the board so as to direct the sights on A; the board is now "set." Pivot the ruler on *b*, direct it on B and draw a line *bc*. Pivot the ruler on *c*, aim at C and draw a line *cx*, the point of intersection *x* is the place required.

In interpolating by any of the preceding methods, the accuracy of the determination depends (as in triangulation) on obtaining good intersections at the point, and this idea should guide the surveyor in his choice of stations, by reference to which he proposes to find his place.

It may happen that the shape of the piece of ground is such that the board will not contain it when "set" by the magnetic needle, as first described, with the sides of the board north and south (Fig 20, I).

I. FIG. 20. II.



In this case the board being first placed in such a position that it *will* contain the sketch (II), the compass box will be withdrawn from underneath and laid on the sketch in such a position that the magnetic needle points to the index.

A line NS will be drawn along its edge. The triangulation is then proceeded with.

In setting up the board subsequently at any time by means of the compass, the box is readjusted to this line, and the board revolved until the needle points to the index.

SECTION V.

The Prismatic Compass.

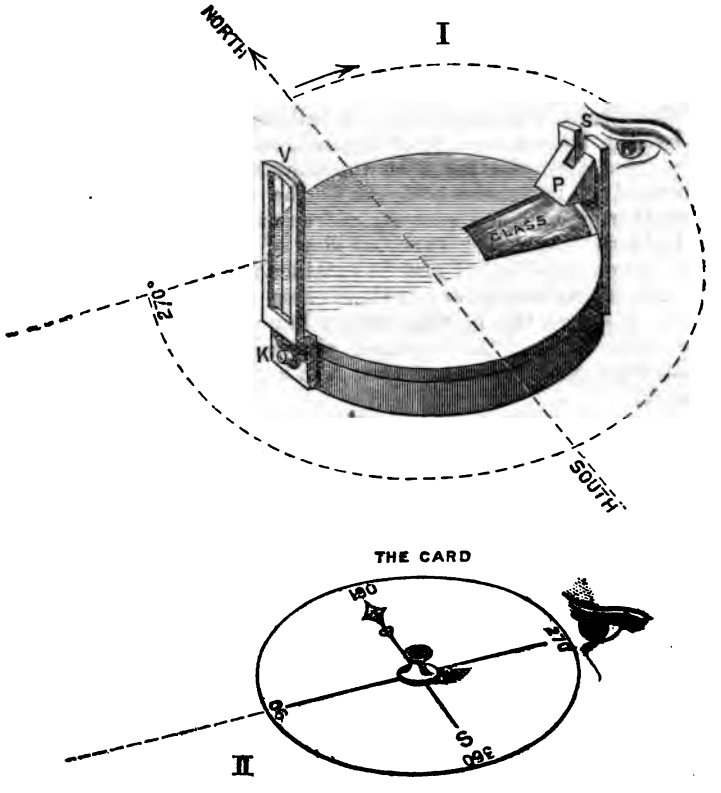
This instrument consists of a magnetic needle balanced on a pivot, and carrying a card divided into 360° and half degrees: contained in a metal box, at opposite sides of which are a sight vane, V, and an eye-piece, S (Fig. 21).

The box is generally fitted with a metal cover, in which is a glazed opening, through which is seen the graduated edge of the card reflected by a prism at P to the eye, when looking through the slit S and directing the vane on the object.

The sight vane and prism are turned down when not in use.

The prismatic compass gives the "bearing" of an object, that is, the angle contained between the magnetic north line and a line from the observer to the object, or "angular distance from the magnetic north."

Fig. 21.



In using the compass, first hold it at some distance from the eye, and watch the swing of the card. By pressing the knob K, which touches its edge, check it when nearly midway in its swing. When

quite steady bring it slowly to the eye, holding it horizontally with both hands, so that the card may not touch the cover.

The graduation is read from right to left, like the dial of a watch. The card must be at liberty whilst the observation is being taken, and the knob K must not then be touched.

In windy weather it may be necessary to kneel, resting the elbow on the knee, to get a correct observation.

The graduation of the card commences at south (II, Fig. 21), in order that the degree showing the bearing of the object may appear under the eye. Thus the vane V being directed on an object which is 270° from north, measured from right to left (I, Fig. 21), it is that number measured from south which appears under the prism.

The compass cannot be relied upon for great accuracy, the presence of iron ore in the ground or other disturbing influences, may affect it to such an extent as to render it almost useless in some localities. However in England it will seldom err more than 2°, a quantity which, in mere sketching, is not very important.

Portability is the chief merit of the instrument. It is very convenient for rapidly filling in the details of ground, particularly when the country is close, and the view limited.

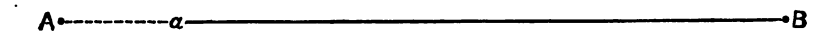
The whole of a sketch should be executed with the same compass, as different instruments will vary as much as 3 or 4 degrees. The magnetic variation of the instrument being ascertained, the true north can be laid down on the sketch (page 44). No observation should be taken with the compass in close proximity to a mass of iron, such as a gate.

The effect of the attraction of a railway may be avoided by taking the bearing from a point 20 or 30 yards on one side of it, and protracting it from a similar point on the sketch; or the deviation may be minimised by using the compass in the centre of the six-foot way, where there is an equal quantity of iron on either side.

In hurried work the expected view of one station from another is often not obtainable, but may be obtained from a point close by. The compass is very convenient in these cases.

For instance, the bearing of any line will be constant throughout its length, so that the required observation may be obtained by advancing a short distance, as from A to *a* (Fig. 22), (B being invisible from A).

FIG. 22.



The surveyor may place himself on the line between two distant points by laying a straight stick on the ground, and observing from either end, whether it is directed on one of the distant points, shifting its place to the right or left until he finds it to coincide with the line between the points on the ground (as explained in connection with the plane table). Having thus found the line, the bearing of either of the stations may be observed, as if the observer were standing at the other.

In using the prismatic compass for observing a triangulation, the base having been selected and measured (as already described), a list of the objects is first prepared, and the bearings are entered opposite them, as they are observed. In this way a record is kept, so that the work can be revised and checked; also the bearings can be more rapidly protracted than if each observation were separately laid down immediately after being observed, as all the bearings can be marked

off along the edge of the protractor when once adjusted on the sketch.

The bearings of two stations may be taken one immediately after the other without removing the compass from the eye, if the memory can be trusted.

The Protractor.

The direction of an object observed with the compass, being expressed in degrees of angular distance from the magnetic north, must be laid down on the sketch with a protractor, a more troublesome process than drawing its direction as described with the plane table.

The sketching protractor is a thin rectangular slab of ivory, about $6 \times 1\frac{3}{4}$ inches, with bevelled edges.

The degrees of the semicircle from 0° to 180°, that is, from north to south, by the east, are marked on the outer edge of the protractor; the western semicircle is figured inside these from 180° to 360°. The centre is marked by a broad arrow.

Smaller quantities than degrees must be laid down by estimation.

The sketch must be prepared with parallel lines, about one-third of an inch apart, to represent the magnetic north and south, with relation to which the bearings are protracted.

One end of these meridians should be marked N before commencing the sketch, to avoid the possibility of protracting the bearings in the reverse direction.

The protractor is laid on the sketch with its centre at the point where the bearing is to be drawn, and its edges set north and south, or parallel to these lines. There should be no difficulty in recognising this parallelism, as one edge of the protractor cannot be farther than one-sixth of an inch from a line.

If the bearing is under 180° the graduated edge of the protractor is laid to the right; if over 180° to the left, the north margin of the sketch being uppermost.

The bearings of a triangulation (Fig. 23), observed with the prismatic compass, as explained, are thus noted:—

At A	C, 3°	At B	F, 181°	At G	K, 310°
	D, 40° 15′		G, 220° 15′		L, 66° 15′
	E, 60°		H, 231°		
	B, 85° 45′		A, 265° 45′		
	F, 110°		C, 309°	At D	L, 120°
	G, 141°		D, 315°		K, 242°
	H, 171° 30′		E, 350° 30′	At F	—C, 332° 45′

A point is chosen for A in such a part of the paper that there may be room for the whole sketch on it.

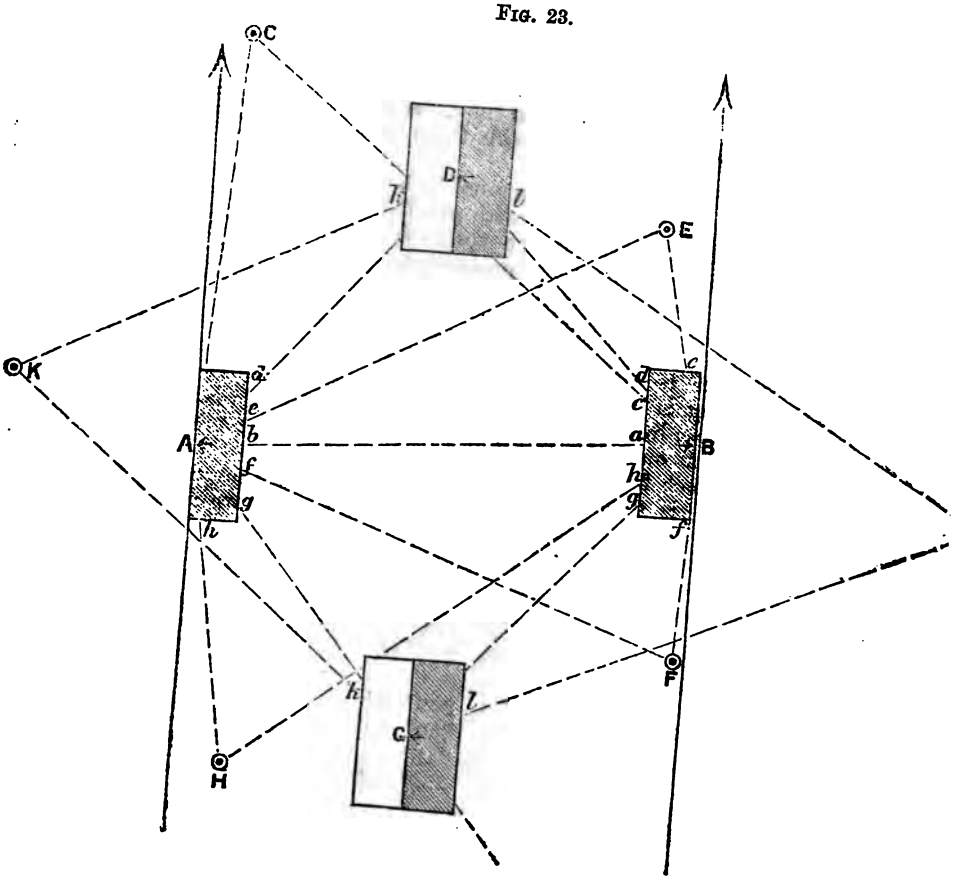
The protractor is adjusted, with its centre at this point and its graduated edge to the east. The position of all the bearings under 180° are marked off, and fine lines of indefinite length drawn through them from A, as shown; those over 180° are next protracted.

The measured length of the base being taken along AB, according to the scale of the sketch, the centre of the protractor is set at B, and the observed bearings protracted.

There is no necessity to draw lines throughout from B to intersect the relative lines previously drawn from A. It will be sufficient to mark the points where the intersection would take place.

The letter or name by which each station is designated should be

FIG. 23.



marked on the relative lines as they are protracted, in order to avoid confusion.

The observation of C at F was taken as a partial test of the accuracy of the triangulation. If this be correct, the line FC, when protracted, will pass through C in the sketch, which point was previously determined from A and B.

The protractor has on the reverse side the normal scale of slopes (being that most frequently used for placing contours in the field), the vertical interval and the horizontal distance varying inversely with the plan scale, as explained (page 21). Tables of distances in yards suitable to the normal scale of slopes at plan scales of 6 and 12 inches to a mile are also engraved on the protractor.

If required to sketch ground with contours at abnormal vertical intervals, the surveyor must construct a scale of slopes on the edge of a card for use in the field, as described (page 20).

The scale of 6 inches to a mile engraved on the protractor may be used for sketching on other scales of which it is a measure or multiple by simply multiplying or dividing the measured distance as required. Thus, for instance, in sketching at 3 inches to a mile, the measurements would be halved, or in sketching at 18 inches to a mile trebled, and in either case taken off the scale of 6 inches to a mile.

The point at which the angle is to be laid down, may be so near the edge of the paper that the graduated edge is off it. In this case lay the protractor with the graduated edge inwards, and produce the required angle outwards *through* the centre.

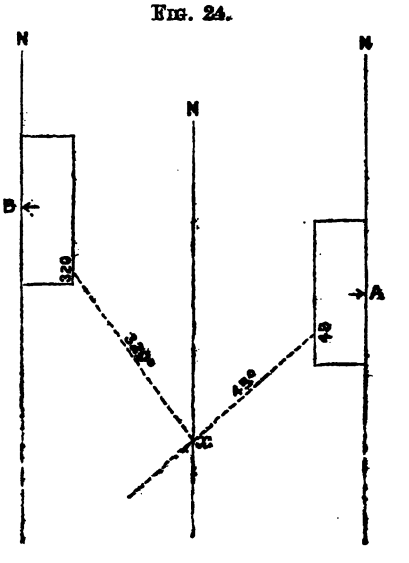
Interpolation.

With the prismatic compass, the place in the sketch corresponding with that on the ground may be easily interpolated when two distant known stations are visible.

If the bearing of a Station A (Fig. 24), be, say 45°, then the observer's place on the sketch is in such a position with reference to A that the bearing 45° when protracted would pass through it.

The simplest way of determining this line is to protract 45° *at A*

FIG. 24.



in the reverse direction (with the graduated edge of the protractor to the left instead of the right).

Supposing the bearing of the other station B to be 320°, this would be laid off at B, but reversed, or to the right.

The intersection of these two lines determines the observer's place *x*.

As previously remarked, this operation is often useful in finding the position of a cross road, or other convenient starting point, or for checking the accuracy of a traverse.

The accuracy of the determination depends on securing a good intersection, not too acute, at the point *x*.

The Magnetic Variation.

The magnetic needle in various parts of the world deviates more or less from the meridian: this angle of deviation, or angle formed by the needle with the true meridian at any place, is called the "variation" or "declination" of the compass.

There are only two lines on the earth's surface where the magnetic and geographical meridians coincide.

In the South of England, in 1882, the needle points about 18° 20′ west of north.*

The variation of the needle is so inconstant that the bearing of any line observed with a compass can only be considered an approximation to its true direction.

The needle is liable to disturbance from the effect of iron-ore in the ground, a serious difficulty, because unseen. In Zululand this local attraction is said to have rendered the prismatic compass useless for sketching. Visible causes of deviation, such as iron gates, girders, &c., can easily be avoided or compensated for.

The needle further undergoes diurnal irregularity (different in summer and winter). In summer in England, from sunrise till about midday, the needle moves westwards about 15 minutes, then returns gradually to its original position about 10 P.M., where it remains until morning. The magnetic variation in England is tending annually northwards at the rate of about five minutes.

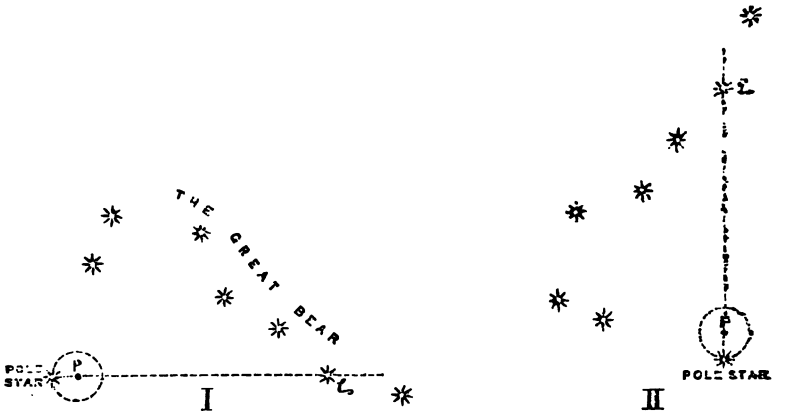
The natural direction in which the needle points in England is about 70° downwards. This tendency, known as "the dip," is counteracted by weighting the opposite end of the needle. The dip varies in all parts of the world; at the magnetic poles the needle would point vertically downwards; about the equator dip is imperceptible. The object of mentioning this tendency of the needle is because it may be found necessary to alter the counter-balance of the compass card in different parts of the world by weighting the elevated end with a little sealing-wax.

The magnetic variation of each compass should be known, in order that the true north may be laid down on sketches, to which line all the work of different officers employed in the execution of a combined survey may be referred, or by which the relation of sketches to existing plans may be compared.

* The magnetic variation in London in 1576 was 11° east. Thence it receded northwards, and in 1660 coincided with the meridian. Still moving westward, the greatest variation, 24° 20′, was attained in 1814, since which time the needle has been returning northwards.

The pole star furnishes the simplest means of determining without special instruments the true meridian, and thence the magnetic variation.

FIG. 25.

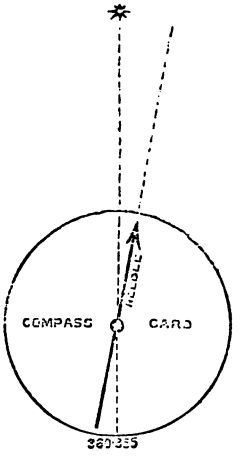


The heavens appear to revolve round an invisible point (the pole) only 1° 27′ distant from this star. Twice in every 24 hours the pole star in revolving round the pole comes into the same vertical plane with, and either above or below, it. This occurs when the star ζ of the Great Bear (the second from the end of the tail) is in the same vertical plane with the pole star (Fig. 25, II).

At this time the bearing of the star should be observed with the prismatic compass, a candle being placed so as to illuminate the card.

The angular distance of this bearing from true north is recorded as the magnetic variation of the compass; for instance, if the bearing were 355° 15′ the variation would be 4° 45′ east (Fig. 26).

FIG. 26.



The relation of the magnetic to the true meridian is often misconceived; it may be best realised by first drawing a line on paper to

represent the true meridian, and then laying a protractor with its centre on this line, and the given bearing coinciding with it. The edge of the protractor is now magnetic NS.

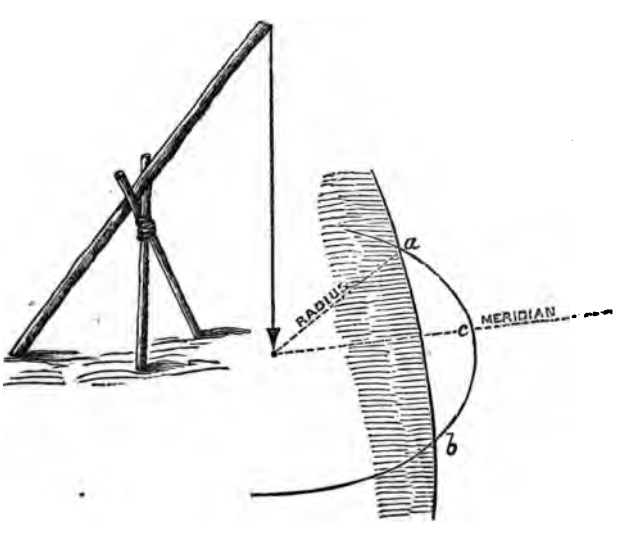
If it be inconvenient to wait for the star ζ, Ursæ Majoris to come to the same vertical plane as the pole star, the bearing may be taken when the two stars are in the same horizontal plane. In this case the true north is 1° 27′ east of the pole star if the Great Bear is east of it (Fig. 25, I) and *vice versâ*. This quantity must accordingly be added to, or subtracted from, the observed bearing.

A convenient manner of laying down the north without special instruments, is to hang a plumb-line from the top of a window which looks northward. When the north star is on the meridian, stick a needle in a table in the exact line with the string and star : a flag or other mark may be placed by daylight, marking the meridian in the same alignment, at any distance.

Another method of laying down the true north is by the sun. Were it possible to note the moment that the sun attains its greatest elevation in the heavens its direction (true south) might be laid down at once. But as this moment of culmination is difficult to determine without astronomical instruments, it is more practical to do so by the method of equal altitudes, which can be accomplished without instruments.

A pole is stuck lightly in the ground, its head pointing somewhat northward, and kept in position by two sticks tied together (Fig. 27): a perfectly level surface should be prepared beneath it. About half an hour before noon the extremity of the shadow projected by the pole should be marked (*a*.) Find the point vertically under the top of the pole by a plumb-line hung from it; describe an arc with radius of the length of the shadow from this point as centre.

FIG. 27.



When the shadow after getting shorter and shorter, again lengthens until it touches the arc, mark the spot (*b*). The point of bisection of the arc (*c*) between *a* and *b* is true north of the centre.

A flat surface, such as the top of a camp table laid on the ground and levelled, permits the direction to be more accurately determined.

Questions.

1. What would be recorded as the magnetic variations of compasses from the following observations:—
   (*a.*) The bearing of the pole star when on the meridian being 345° 30′;
   (*b.*) The bearing of the sun at noon on the meridian being 189° 15′.
2. Draw A and B two points 3 inches apart, the bearing of B from A 327°, and the magnetic variation 20° W. The north point to be drawn in accordance with the authorised conventional signs.
3. What would be the bearing of the sun at noon observed with a compass having a magnetic variation of 17° E.?
4. The bearing of the pole star being observed 343° 30′ at the time that ζ Ursæ Majoris is at the same altitude with, and east of it, what is the magnetic variation of the compass?

SECTION VI.

Traversing with Compass. Field Book.

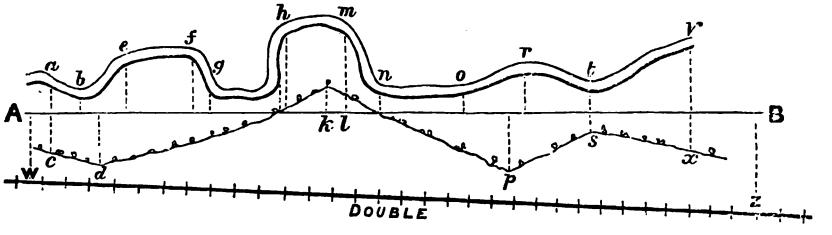
"Traversing" is the operation of measuring the length and observing the direction of a series of straight lines along a road, or through a country; also the position of adjacent objects with reference to these lines, which are termed traverse lines" or "chain lines."

The traverse, or survey of the details of the ground, is sometimes performed by entering the observations and measurements in a field book, from which the plan is subsequently *plotted*, or drawn.

The field book is a large pocket book with a column about three quarters of an inch wide, ruled lengthways down the centre of each page; this is called the *chain column* (whether the chain be used or no); in it are only booked the *forward angles*, or direction of the traverse lines, and the forward distances.

The side columns are used for the *offsets, or measurements made perpendicular to the traverse lines.* It is by means of offsets that most of the details of the ground are measured. For instance, to survey a sinuous line, such as a stream, or an irregular fence, the bearing, or forward angle of a traverse line AB is observed as nearly parallel to, and as close to it, as circumstances will allow, and offsets or short per-

Fig. 28.



pendiculars are measured to the points *a*, *b*, *c*, *d*, &c., which best define the form of the objects. In regular surveying, these offsets are measured with a tape or rod, but in sketching it is usually sufficient to judge their lengths. Offsets are not, as a rule, taken to objects at a greater distance than 100 yards from the traverse line; the length of offsets depends somewhat on the scale, and also on the time available.

Before observing the direction of a traverse line, one should consider the necessity of its being generally parallel and conveniently near to the stream (or whatever the object may be), and should also bear in mind that the work must be done with as few changes of direction as possible. It is evident that it is not necessary to take offsets to more points than two in a straight line, however long it may be; the offsets W, Z, determine the position of the railway with relation to the traverse line AB (Fig. 28).

The forms of the objects so measured are sketched in the offset

columns, their peculiarities of shape being often exaggerated so as to convey more clearly the particular points to which the figures refer. The entry in the offset column is made on the same line as the forward distance in the chain column opposite which it occurs.

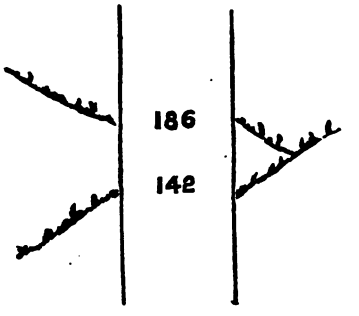
In the offset columns are also entered the bearings of objects too distant to be conveniently fixed by offsets.

The entries are commenced at the bottom of the last page and continued upwards towards the beginning.

The figures should be legibly printed so that the book may be "plotted" by a second person; the entries should not be crowded.

The chain column represents a line having no breadth, therefore no representation of the sides of the road or any other detail must be made in it; if in traversing, a road or fence is crossed obliquely, it must not be represented in the field book as passing obliquely across the chain column, but must arrive at one side of the column, and leave it at the other, at points precisely opposite, thus:—

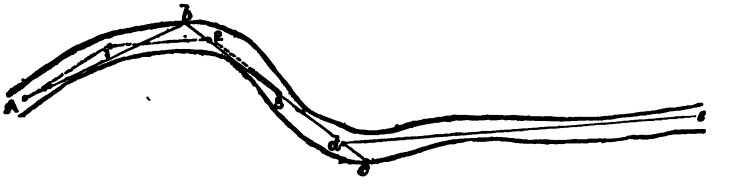
FIG. 29.



As all the figures refer either to linear measurements, or to their direction, the latter must always be distinguished by the signs of degrees and minutes, so that they may not be mistaken for linear measurements; some persons use a red pencil for the angles, and a black for the distances.

Winding roads should be traversed with the smallest possible number of observations.

FIG. 30.



Thus, instead of following the centre of the road by a number of short traverse lines, 1, 2, 3, &c. (Fig. 30) the forward angle should be taken on *b*, the most distant point visible from A; after traversing up to *b*, the next forward angle would be taken on *c*; in this line *bc* it may be found that a longer view of the road towards *e* is obtainable from *d* than from *c*, so that the next forward angle is observed from the former point.

The different places at which the direction of the road changes and is observed with the compass, are denoted thus ⊙, called stations.

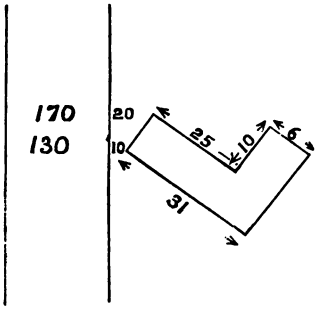
When a fresh forward angle is observed, a line is drawn across the chain column above the last forward distance.

Each ⊙ is designated by a Roman numeral. The forward measurement is commenced afresh at each ⊙, but all intermediate measurements are inclusive.

Offset measurements are all taken from the chain line (that is, when two or three objects are on the same offset line, the distance of each from the chain line or traverse line is recorded).

In surveying buildings on a large scale, it is generally desirable to measure their details along the walls, in which case they are distinguished thus ⟨100⟩, as shown:—

FIG. 31.



Before pacing an offset, a mark should be left at the spot so that the forward measurement may be resumed there.

The field book must be held with the chain column corresponding in direction with the forward angle, and care taken that objects to the right and left are entered in their respective offset columns.

As an illustration of the method of working and of keeping the field book, a portion of road drawn on a large scale is shown, the forward angles and offsets are dotted. Plate II.

The traverse is commenced at ⊙I, the first forward angle taken up the road on a direction post at ⊙II (42° 30′). This is the first entry made in the chain column. The offsets are measured to the boundaries of the road 6 yards on the right, 5 on the left. These entries are made on the same line as ⊙I in their respective offset columns.

The forward pacing is then commenced, care being taken not to deviate from the line of direction. At 32 yards the line touches the left boundary; this is shown in the book, not by drawing the boundary to touch the chain line, but by the entry 0. The right boundary is 10 yards distant here.

The field book shows the remainder of the offsets up to ⊙II. On reaching this spot, a line is drawn above the last entry 83.

The name of this place ⊙II is next entered. Bearings are taken of the road to Mostyn, and of a farm chimney at some distance. These are entered in their respective side columns. The farm is subsequently observed again from ⊙III; the intersection of these bearings fixes its position. Another bearing from ⊙IV intersecting the same point on paper, when laid down, shows that both it and ⊙IV are correct.

The necessity of having a good angle at the point of intersection

principle, but the traverse is merely drawn at once with the protractor instead of being written in the field book.

The sketch should be held in the hand (not attached to the body by a strap) and should be turned so that the forward angle on paper corresponds in direction with the traverse line on the ground; this enables the draughtsman to realise the connection between them.

The forward angles should be lightly drawn, as they do not remain permanently on the sketch.

Unnecessary prolongation of lines should be rubbed out, so as to avoid confusion.

The points at which fresh forward angles are observed and pacing re-commenced in the traversing, should be surrounded with a small circle, or otherwise distinguished in the sketch, so as to avoid the common source of error of laying off distances from the wrong point.

After halting to sketch or to measure an offset, the counting of paces is to be resumed at the last number, not at zero, except on starting to measure a fresh traverse line.

SECTION VII.

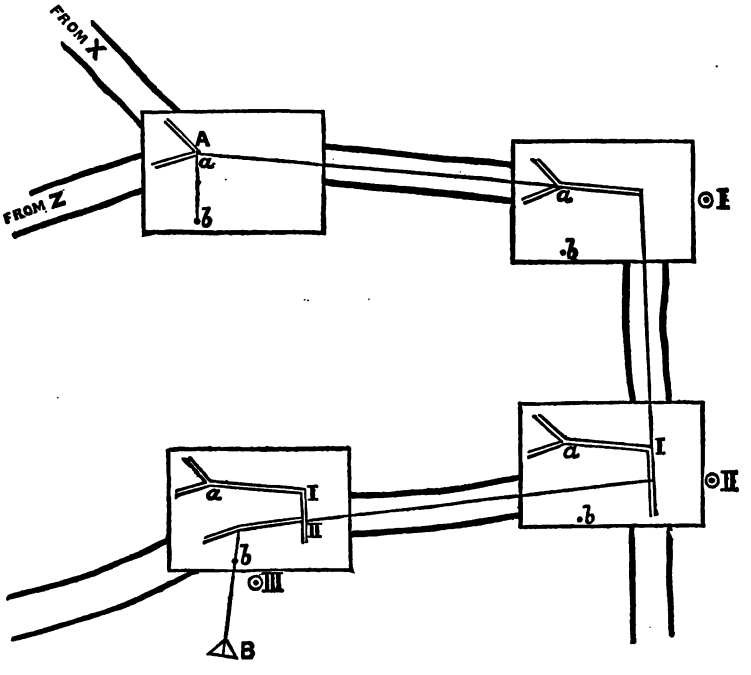
Traversing with the Plane Table.

It has been previously remarked that in "filling in" the details of a survey, the work should be referred as much as possible to the stations fixed by triangulation, and should therefore be commenced at one of these stations, with the intention of working up to, and closing on another.

This may not be possible in some cases, and the starting point for a traverse may have to be found by interpolation when the station is inconveniently situated or inaccessible. If the plane table can be set up within a short distance, 50 yards or so, of such a station, this distance may be estimated and the starting point taken on the paper at the corresponding distance and direction.

In the following description, the points where the plane table is set to observe a change of direction in the road, will be designated thus ⊙. A and B, Fig. 32, are two of the stations fixed by triangulation. The

Fig. 32.



traverse was commenced at A. The needle was fixed in *a* on the sketch, the ruler adjusted to the line *ab* and the board revolved, until the sights were directed on B, then clamped. The sketch was thus "set," and if the magnetic needle were examined, it would be found to point to the index, as it did on commencing the triangulation.

The sketch might have been set by the magnetic needle instead of the line AB, on starting, but this method would not have been so accurate.

The ruler was next directed up the roads X and Z, and these were drawn their proper width, according to scale. Also down the road on a well-defined object, the more distant the better, in the required direction through ⊙I.

Before commencing the forward measurement, all the detail immediately adjoining was sketched, such as fences, houses, &c., their direction being determined by the ruler and their distance either by pacing or estimation, generally the latter. (This detail has been purposely omitted in the diagram.)

The forward measurement was then commenced, care being taken to preserve the exact line in advancing. The detail on either side was drawn from time to time, the surveyor halting to estimate the distance of objects, as soon as they became perpendicular to the forward direction, as he advanced.

On reaching ⊙I and placing it at its measured distance from A in the sketch; the change of direction towards ⊙II was thus laid down. The ruler was adjusted to the traverse line, and the board "set" by revolving it so as to direct the sights on A, then clamped. The ruler was then aimed at ⊙II and the forward direction drawn.

In order to follow the changes of direction accurately, it is necessary, as a rule, to leave at the back ⊙ some mark which will be visible from the forward ⊙, such a piece of paper fastened in the hedge. Also to select some well-marked object for the forward direction, as distant as possible, and to be careful to set up the plane table exactly in this line, on arriving at the forward ⊙.

The traverse may occasionally be checked by aiming the ruler at any station that may be visible at the time the sketch has been "set," and observing whether the edge passes through the point which represents this station on the sketch whilst pivoted against a needle stuck in the point of observation. The magnetic needle may also be consulted occasionally to see whether it points to the index after the board has been set by the back ⊙.

The traverse was thus carried on to ⊙III, where an opportunity occurred by closing on station B, and throwing out any error that might have crept into the work.

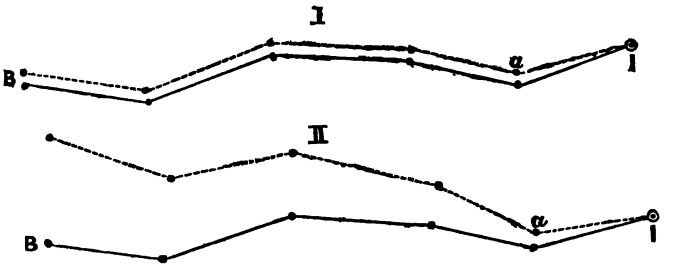
Instead of setting the board by the back ⊙ as above described, it may be advantageous to set it merely by the compass when traversing through a wood, or in tortuous lanes, where it would be necessary to observe fresh directions frequently.

This method is very simple, and saves the necessity of leaving a visible mark at the back ⊙ from which to measure the forward direction. At each ⊙ the board is merely revolved until the needle points to the index, then clamped, and the direction laid down with the ruler.

The inaccuracy inherent in the compass will produce less evil than will an error of direction of the same amount committed in traversing by the back ⊙, such as is very possible with an inexperienced surveyor. For instance, an error of direction *a*, committed with the compass at ⊙I will eventually only affect the traverse by the same amount (Fig. 33, I).

Whereas a similar error made when traversing by the back ⊙ will increase and radiate with the distance (II). Hence it may be seen that the system employed in traversing should depend on the sur-

FIG. 33.



veyor's skill, and on the nature of the road to be traversed, also on the existence, or otherwise, of local attraction, ironstone, &c.

SECTION VIII.

Hill Sketching.

Before the application of contours to hill sketching was adopted, the shape of the ground was drawn in hâchures on the spot, a system in which everything depended on good draughtsmanship and neat execution, guided by fixed rules difficult to apply in cold or bad weather.

The object of the present system is—

1. To represent the ground with as little drawing as possible in the field, time being too valuable for the exercise of mere draughtsmanship.

2. To give a more exact and scientific representation of the features than was formerly possible.

It is evident that the contour system requires more thought and judgment in the field, though less preliminary instruction indoors.

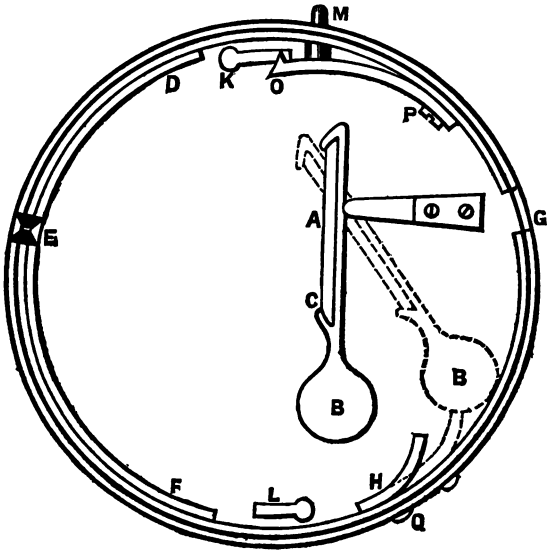
In order to sketch ground intelligently it is essential that in the first place the surveyor should form some conception of the shape of the features, and of the general appearance they will present in plan, before he proceeds to the application of measurements. This may appear difficult to a beginner, but every day's work will strengthen his powers of observation and add to his ability to express his ideas graphically.

It would be impossible to prescribe one system of determining the position of contours which would be equally applicable to all sorts of ground. All that can be done is to explain a few of the most usual methods, to be employed as experience may suggest.

Watkin's Clinometer

is the instrument used in sketching, both for levelling and for measuring slopes.

Fig. 34.



Description.

The above figure shows the clinometer with the cover removed. The pendulum AB which swings freely from the pivot A is fitted with a mirror AC, so as to reflect to the eye placed at E the scale of degrees engraved on the ivory DEF. An object the inclination of which is required is at the same time seen through the opening G. When not in use, the plumb-bob B is kept from vibrating by the metal arm H sliding against it. To fix the instrument on to the compass, slots, K and L are cut in the base, into which enter two screw heads fixed in the bottom of the compass, and locked in position by the spring OP.

Instructions.

To prepare the instrument for taking angles, slide the knob Q to the left to free the plumb-bob; hold the *clinometer* in the *left* hand, and view the object through the opening G, noting the angle opposite, as seen in the mirror.

To remove the instrument from the compass, hold the *compass* in the *left* hand, press the knob M, and turn the clinometer to the right (*i.e.*, in the same direction as the hands of a watch).

To place the clinometer on the compass, enter the projecting screw heads into the openings K, L, then pressing the instrument well against the compass, turn it towards the left until locked by the spring.

For travelling, tilt the clinometer until the plumb-bob rests against the side (as shown in dotted lines) and slide H until it presses against it.

In observing a slope, the line of sight must be directed paralled to the surface of the ground. When no object presents itself of the same height as the observer's eye, he should stoop or kneel, so as to reduce the height for which allowance has to be made.

For levelling. Observe some object the same height as the eye, which coincides with 0 in the clinometer.

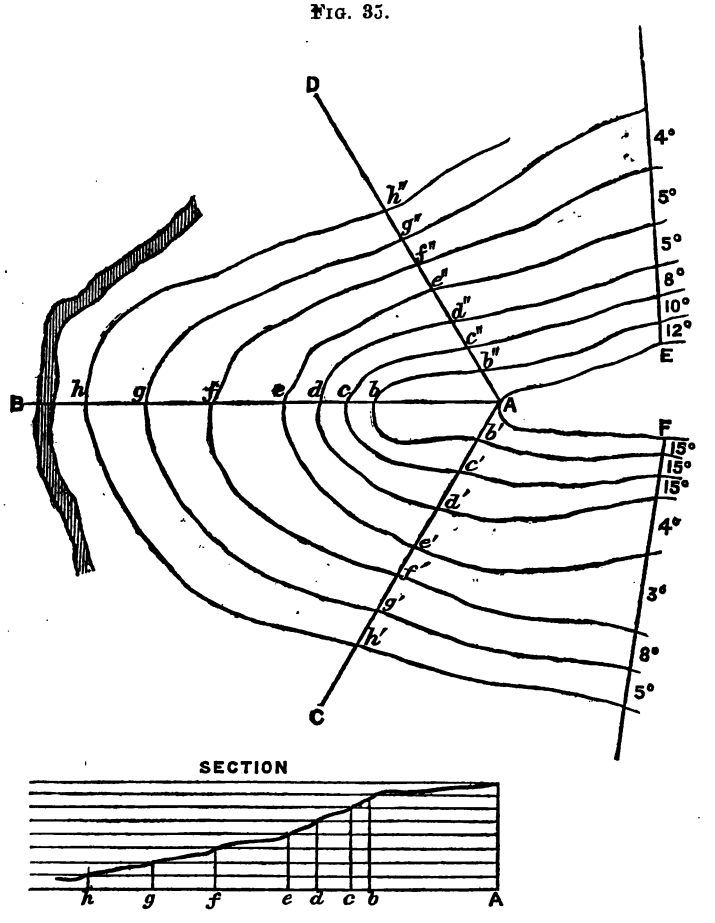
When the observation is made at a distance of more than 300 yards or so, the observer's height is so small in comparison with the distance, that it is hardly worth while to make any allowance for it.

We will suppose that the preliminary triangulation has been executed, and the sketch so far completed as to show the roads, fences, and other details; these objects will greatly assist the operation of hill sketching; as the direction of watersheds, valleys, and other hill features can often be recognised with reference to them, without employing the compass.

Supposing the sketch is to be made at the scale of 12 inches to a mile, and the hills shown according to the normal scale of slopes which is given on the protractor, the vertical interval between the contours will then be 10 feet (page 21).

A simple salient spur might be sketched thus.

FIG. 35.



Standing at A, the slope is observed with the clinometer to be 2°, in the direction of B. Referring to the table of distances on the protractor, it is seen that, at that inclination, the next contour, 10 feet below A, will occur, 95 yards down the slope.

The observer now paces to this point *b*, and marks the corresponding distance on his sketch, using either the scale of slopes on the protractor, or laying off 95 yards at the scale of 12 inches to M.*

The length of the pace must be sensibly reduced in measuring down steep slopes, and increased in pacing up hill.

At *b* the slope becomes steeper, and is observed 10°. The horizontal equivalent (19 yards) is paced forwards, and it being found that the slope continues constant for at least 57 yards, it will contain three contours, *c*, *d*, *e*.

At *e* the slope decreases to 3°, so that a further fall of 10 feet will occur in 63 yards at *f*.

* It will be remarked that the horizontal equivalent is the base, whereas the corresponding distance measured on the ground is the hypothenuse. The difference between the hypothenuse and base, however, is so small at low gradients as to be inappreciable when the measurement is made by pacing. At 10° of slope the difference, for instance, is only 1½ yards in 100.

Here it is noticed that the slope is constant as far as the stream, the position of which is supposed to have been already drawn on the sketch. Being measured 4°, it is not necessary to pace the horizontal equivalent, but merely to set off on the sketch as many repetitions of 48 yards as there is room for between *f* and the stream (in this case two, *g* and *h*).

In describing these operations, the lines along which the measurements are made will be termed "section lines."

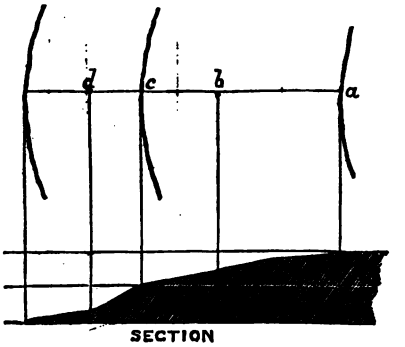
Supposing that the slope on the section line AC is observed to be 6°, for a distance judged to be at least 300 yards; points *b'*, *c'*, &c., may be marked off 32 yards apart, at the same levels as *b*, *c*, &c., and the contours drawn joining these points as represented. Likewise the slope of the ground on the section line AD being 8°, the contours are placed 24 yards apart at *b''*, *c''*, &c., and connected with those first determined.

Again, if the surveyor can by means of his instruments find points E and F (Fig. 35) on the same level as A, he can, by observing the slopes, set off other points belonging to contours *b*, *c*, *d*, &c., and join them to these, with due regard to the form of the intermediate ground.

In practice some difficulties will occur in applying this system, as the slopes gradually merge one into the other, so that it cannot be said that a change of slope commences at any particular spot. A little practice soon enables the surveyor to overcome this difficulty, but a beginner may do so mechanically by the use of his instrument. For instance, supposing the upper part of the slope (Fig. 36) to be observed 2°, the horizontal equivalent of which is 95 yards; after advancing 42 yards to *b*, it is noticed that the slope becomes steeper (4°), the remaining half of the vertical interval between the contours belongs to this slope, the equivalent of which being 48 yards, the contour is reached by advancing 24 yards.

At *c* the slope is 8°, horizontal equivalent 24 yards, but on measuring to *d* 16 yards, or $\frac{2}{3}$rds of the distance, it changes to 3°, so that the contour is reached by measuring 21 yards further ($\frac{1}{3}$rd of 64 yards). This is so troublesome a process, that it should be rarely undertaken. When the vertical interval between the contours is small (20 feet or so) it is easy to make allowance for any slight alteration of slope, in observing it with the clinometer. In fact, before actually observing a slope, one should first estimate roughly the distance in which the required fall (whatever it may be) will occur.

FIG. 36.



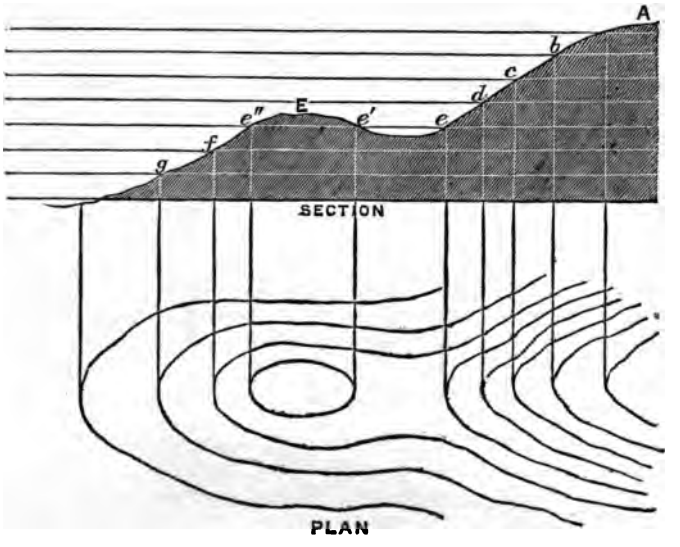
This is easy when the slope is concave in section, because all the surface is visible, but when convex (Fig. 37) a small part only of the ground *ac* can be seen. Even in this case, one may after a little practice form a just conception of the approximate position of the contour, although unseen, and observe the slope *ab* accordingly with sufficient accuracy.

FIG. 37.

In the case of an outlying feature E (Fig. 38) rising in front of the surveyor, as he descends from the high ground A. On reaching contour *e*, he finds by the clinometer that (making due allowance for the height of his eye above the ground) this contour will strike the knoll at *e'*; keeping his eye fixed on this point, he measures across to it, and also to *e''*, which he judges to be on the same level, and thence resumes the observations necessary to place contours *f*, *g*, &c.

It is usually better to follow the section lines down than up hill, because a larger view of the ground can be obtained, and the formation of the features more plainly observed. For the same reasons the section lines should as much as possible follow the watersheds of

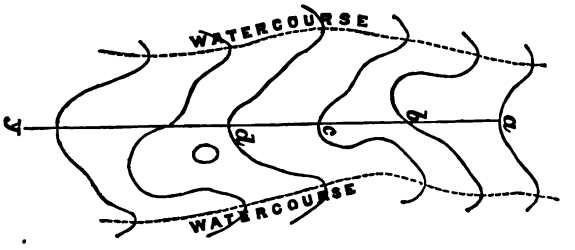
FIG. 38.



features whence a view is more or less obtainable on either side down to the watercourses which bound them. When the surveyor halts on a contour, he should generally hold his sketch in a position corresponding with the country (that is, with the section line on paper directed to correspond with the same line on the ground), and looking towards the high ground, he should trace the contour to his right and left as far as it is in view. The beginner may require to search the ground in his vicinity with the clinometer, in order to recognise his level; but he will soon learn to dispense with this assistance.

Working down the section line *ay* (Fig. 39), after measuring the slope, laying down the horizontal equivalent, and pacing the corresponding distance to *b*, as described, the sketch is held at *b*, with the line *ba* directed towards *a*; it is then seen that the level *b* crosses the section line *ay* obliquely, coming to it from the right front, turning

FIG. 39.



on the watershed to the left, and doubling back in the watercourse about 150 yards to the left front. At *c* the contour crosses again obliquely, coming now from the left front, turning sharply near *c*, and running back towards *b* for some distance. The distances and directions of these bends in the contours are, as a rule, merely estimated.

In all hill sketching it will be found a good plan, before drawing the contours, to indicate the estimated position of the watercourses, which bound the feature (Fig. 39). These can usually be seen and their distance judged on either side from the watershed, they may be indicated by a faint blue chalk line, to distinguish them from other detail. Each contour will take its extreme inward bend on these lines.

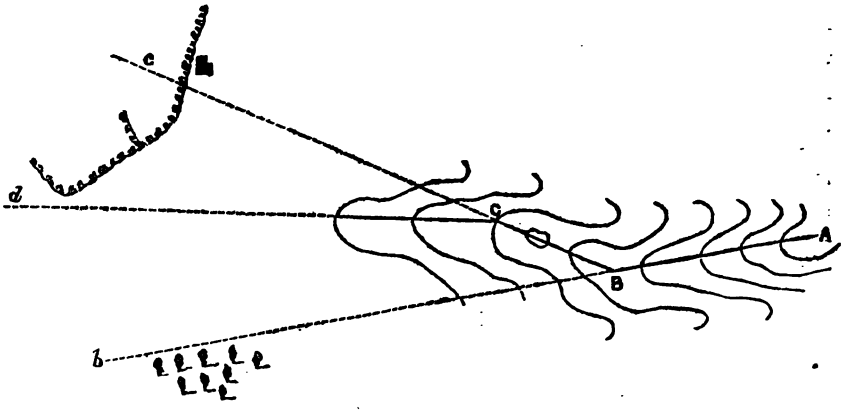
It may here be remarked that the distance of all hill features, up to 60 or 80 yards, should, as a rule, be *judged* when sketching; it would be a waste of time to measure such details by pacing. Further, much time may be saved by impressing on the mind the space (according to scale) which such small distances will occupy on the sketch, and thus avoid frequent use of the protractor.

When the features are very large (as in the chalk formation), and the position of the contour can be observed to right or left to a distance of quarter of a mile or more, it may be worth while to take its direction with the compass occasionally; its distance may be drawn by estimation, subject to correction as opportunity may occur.

It has been remarked above that the section lines should follow the watersheds of features, as a rule; but as these features seldom run in a straight line, it may be necessary to alter the direction of the section line from time to time, so as to follow them. In many cases the direction can be referred to distant points, which have been already laid

down in the sketch, and thus the necessity of observing it with the compass may be avoided. Thus (Fig. 40)—

FIG. 40.

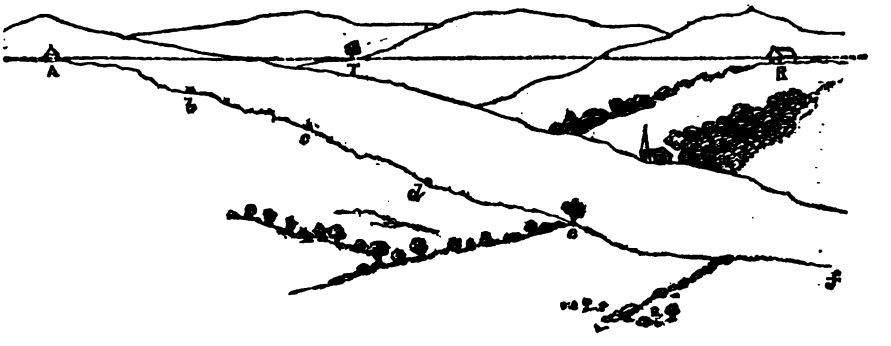


The section line A*b* is drawn a little to the right of a group of trees, which are recognised as laid down on the sketch during the earlier processes. At B it is found necessary to change direction to the right, the section line is produced towards *c*, a little to the left of a house in the distance. At C again the direction is altered to a line which runs nearly direct on the corner of a fence *d*, previously drawn. This system, though not very accurate, is sufficiently so for the purpose of tracing the direction of an imaginary line such as watershed.

In the foregoing description it is shown how the contours of a single feature may be sketched. But if the sketch contains a number of such features, and it is desired that the contours of each should unite and be continuous, the surveyor must operate so as to commence surveying the contours of each feature at levels common to the others.

For this purpose he may, on commencing the sketch, and when standing on his first contour, examine the ground with the clinometer, to find one or two conspicuous objects within half a mile or so, at the present level of his eye. For instance, commencing at A, he may find that the eaves of the roof R and the foot of the tree T are on a level with his eye.

FIG. 41.



These points are registered in the margin as "reference points" for future use. At any time in the course of the sketch, when A, T, or R happens to be in sight, he can, by observing it with the clinometer, place himself at the original level, moving up or down hill, as may be required, until 0 of the clinometer agrees with the observed reference point. He can then find his place on the sketch by interpolation or otherwise, and commence surveying the contours above and below him, as described.

When the hills are of considerable altitude, it may be worth while to register other reference points at every 50 or 100 feet difference of level, so as to furnish the surveyor with the means of placing himself on a known level, which may be at a more convenient height than that at which he commenced. For instance, supposing the position of the contours, to have been found on a section line at *b*, *c*, *d*, *e* (Fig. 41) on commencing the sketch; when standing at *e* the clinometer shows the top of the church spire to belong to this level; this point, and also the tree *e*, might be registered as "reference points," by means of which the surveyor might place himself again on contour *e* when in a distant part of the ground.

In some localities* there may exist natural levels common to the whole ground, such as plateaux formed by the action of water, presenting well-defined hill crests, but little rounded by weather, and so nearly level as to furnish a contour common to the whole district, and very

FIG. 42.

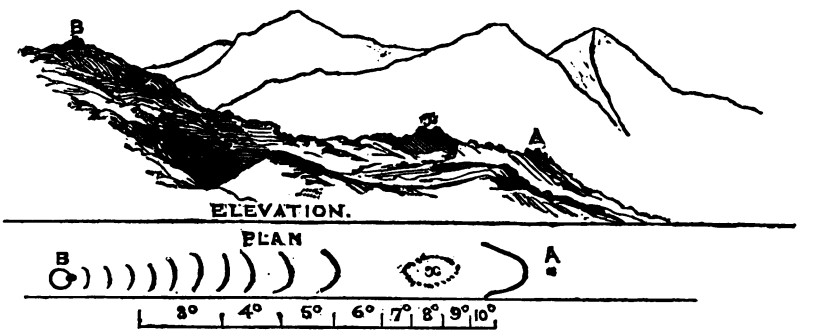
conveniently placed for finding the position of the lower contours (Fig. 42). It is of course necessary for the surveyor in the first place to satisfy himself by the clinometer that such crest is really fairly level.

Again, the ground may contain a lake or a sluggish river, providing a natural level from which the contours should be measured.

A most useful method of employing the clinometer is to determine at one operation the difference of level between any two points, the distance between which is known. If for instance A and B (Fig. 43) have been accurately laid down in the sketch, and the vertical angle of B is observed 6° with the clinometer from A. Supposing the scale 12 inches to a mile, the distance measured on the plan is found 360 yards. Referring to the horizontal equivalents, it is seen that at 6° a difference of level of 10 feet occurs in every 32 yards, therefore B is above A $\frac{360}{32} = 112{\cdot}5$ feet.

* Especially in the neighbourhood of the Royal Military College.

FIG. 43.



Scale of horizontal equivalents for 10 feet, drawn at 12 inches to a mile.

1° = 191 yards.	4° = 48 yards.	7° = 27 yards.
2° = 95 ,,	5° = 38 ,,	8° = 24 ,,
3° = 64 ,,	6° = 32 ,,	9° = 21 ,,

The necessity for even this amount of calculation may be avoided by applying the scale of horizontal equivalents to the drawing, and seeing how many contours at 6° would fit in the distance. In this instance the 11th contour falls a little short of A.*

This decides the *number* of contours, but their *grouping* will be arranged suitably to the steepness in different parts of the slope.

If the slope is seen to be concave (or steepest near the top), the contours will there be grouped closer, as in the figure.

It will be noticed that the accuracy of this system of determining the differences of level, depends on correct knowledge of the distance between the points. Should an opportunity occur of thus observing the vertical angle of the *lowest from the highest* part of the ground, or *vice versâ*, the number of contours, according to the vertical interval which the sketch will contain is checked with certainty.

When sketching in bad weather, this method is useful. The surveyor visits some of the most prominent features, finds his place by interpolation, marks the form as well as he can on the sketch, and writes on them the vertical angle which he observes towards some one central feature. If he has been able to draw the positions of the watercourses, he can finish up his sketch in contours with some accuracy from these data, when he reaches shelter.

For example (Fig. 44, I) part of a sketch executed on a very wet day gave sufficient data for II.

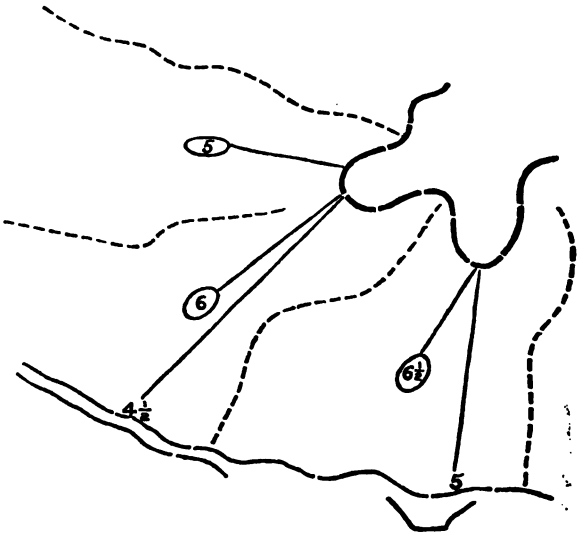
Contours are merely a skeleton outline of the ground, the minimum of drawing, by which it can be represented. It will sometimes happen that an important feature lies between these levels untouched by them; it must be sketched in a dotted line to distinguish it from the contours (as x in Fig. 43), its exact height is not of importance.

The art of hill sketching cannot be satisfactorily formulated. Nothing but experience will produce skill, and an hour or two in the company of an expert surveyor, will advance the student more than weeks of diligent ill-directed practice. The methods described are to

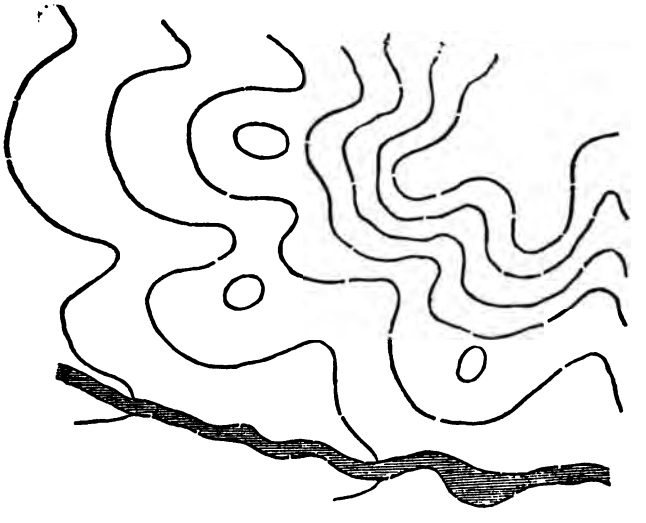
* A rough estimate of the difference of level is made by regarding 6° as equal to 1 in 10 (page 20), so that B is above A 36 yards or 108 feet. The *exact* difference is 113·56, found by employing 3·17 as the divisor (note, page 21). The number 112, arrived at in the usual manner, as explained above, is sufficiently accurate.

FIG. 44.

I.



II.



Scale 6 inches to a mile. 20 foot contours.

be regarded as means to the end of educating the eye and rendering it as far as possible independent of instruments.

MOUNTAINS.

In sketching mountains, somewhat different methods to the preceding must be followed, as the nature of the ground precludes measurement by pacing. Great differences of level here occur in small

horizontal distances, so that the normal scale of horizontal equivalents suitable for expressing manœuvring slopes would crowd the contours unnecessarily and inconveniently. A convenient vertical interval will be about twice as great as that on which the normal horizontal equivalents are based, *e.g.*, at 6 inches to a mile, 40 feet vertical interval, 3 inches, 80 feet, &c.

In arranging the triangulation of a mountain district, the base is generally measured at the foot of the mountain; but when, as is often the case, the slopes terminate in deep ravines, whence no view can be obtained, then a base must be found along one of the watersheds, where there will be probability of finding suitable ground. The highest and most sharply defined peaks will be fixed by intersection, but there may be difficulty even in recognising these from different points of view during the progress of the survey.

If the position of one or two prominent peaks, such as B and D (Pl. III), have been fixed by triangulation; that of less important knolls, as G, E, can be interpolated by reference to them during the progress of the sketch.

Supposing that the survey is to be made at the scale of 3 inches to a mile, and that it has been decided to show the ground by contours at 80 feet vertical intervals, the scale of horizontal equivalents will be as represented in the plate.

The surveyor may have found his place at E, by reference to B and D. Observing the angle of elevation of D to be 10°, it is seen by applying the horizontal equivalents to the plan that there is room for 6 contours; or the same conclusion is more accurately arrived at arithmetically by considering that the distance, 910 yards, contains 6·03 of the horizontal equivalent at 10° (151 yards). Hence the difference of level is $6{\cdot}03 \times 80 = 464$ feet.

Supposing the range of the hills DB to have been already sketched, the 6th contour below D will cut the summit of the hillock E. For the purpose of identifying the contours it is as well to number them. Thus, if the highest contour about D were called No. 20, that at E would be numbered 14.

The general slope observed from E to the bottom of the valley towards D being 35°, there is room for 6 contours. The general slope to the bottom of the ravine towards H being 17°, the contours are placed at an average distance of 87 yards apart, in this direction; notice being taken of a rocky hillock about half way down.

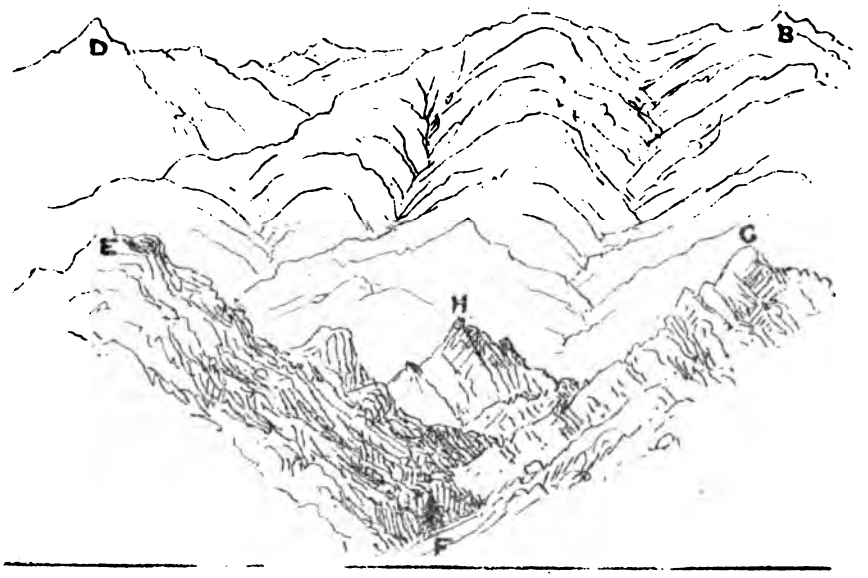
The *direction* of an inaccessible pinnacle H might be laid down, also that of a conspicuous point F in the bottom of the ravine, with the view of subsequently determining their places.

Proceeding now to G the observer's place might be interpolated again from D and B. The lines previously drawn towards H and F might be intersected as shown, and their positions determined.

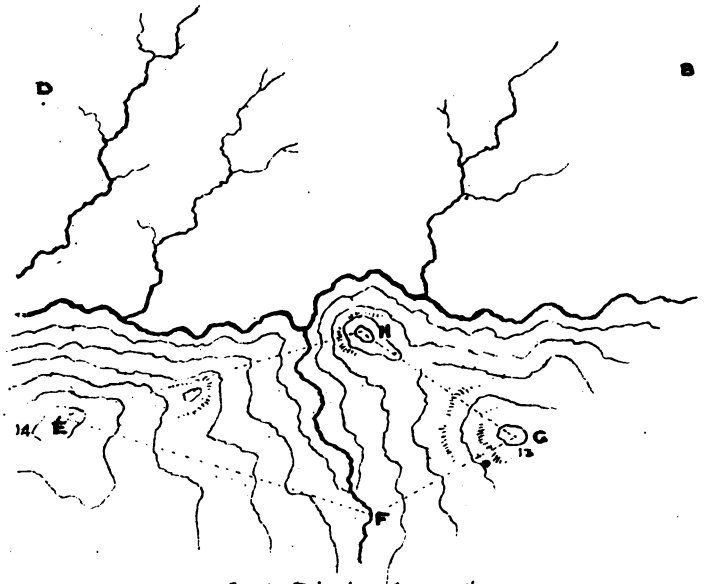
The height of G and the contour to which it belongs might be found by observing the elevation of E or D, with the clinometer as before. Then the angles of depression of F and H show the contours to which they belong, and enable all the intermediate ground to be sketched at sight, the ravine being seen to pass close under H, and there fall into the main valley.

Any remarkable feature such as a cliff which may lie *between two contours* must be indicated by a few touches as shown in the plan. The rocky nature of the ground can be shown by the jagged drawing of the contours.

The general plan of mountain features is best defined by the water-



PLAN



Scale 3 inches to a mile

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 1600 yards

Horizontal equivalents for 80 feet.

1°	= 1528 yards	20°	= 73 yards
3°	= 509	25°	= 57 "
5°	= 305	30°	= 46 "
10°	= 151	35°	= 38 "
15°	= 99	40°	= 32 "
17°	= 87		

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courses which separate them; the direction of these watercourses can generally be observed from the surrounding ridges without descending the mountains; sometimes their direction can be well observed from the opposite side of the valley, as for instance, the watercourse to the left of B (Plate III) from the point where the sketch was taken.

It would be needless further to describe the system, which is capable of many modifications according to circumstances.

The aneroid barometer may be found useful in sketching mountains during settled weather, when no great fluctuations of atmospheric pressure are to be expected. In the Himalayas especially the pressure is so constant that very fair results may be obtained with it.

Mountain aneroid barometers are compensated for temperature, and are furnished with a scale of heights in feet corresponding to the alteration in atmospheric pressure.

A difference of $\frac{1}{10}$th of an inch in the reading of the aneroid, indicates nearly 100 feet difference of level (more or less according to the height above the sea) as will be seen by the following:—

From sea level	to	2,000	feet	0·11	of an inch	{ indicates 100 feet difference of level.
,, 2,000	to	3,000	,,	0·107	,,	,,
,, 3,000	to	4,000	,,	0·1	,,	,,
,, 4,000	to	5,000	,,	0·097	,,	,,
,, 5,000	to	6,000	,,	0·09	,,	,,
,, 6,000	to	7,000	,,	0·089	,,	,,
,, 7,000	to	8,000	,,	0·086	,,	,,
,, 8,000	to	9,000	,,	0·083	,,	,,
,, 9,000	to	10,000	,,	0·08	,,	,,
,, 10,000	to	11,000	,,	0·077	,,	,,
,, 11,000	to	12,000	,,	0·075	,,	,,

The aneroid may be depended upon when the two readings can be taken within such a short time of each other, that the instrument is not likely to have been affected by the changes of pressure. A gust of wind will alter the position of the pointer sensibly.

If on returning to the place where the first reading of the barometer was taken, the observer finds that an alteration has occurred in the pressure meantime, and that the reading is different, he may correct the altitudes in proportion to the alteration and the time that has elapsed, assuming that the change in pressure has been constant.

With an ordinary aneroid and the above table an approximation may be arrived at; a variety of corrections have to be applied in the accurate determination of heights by the mercurial barometer described further on.

SECTION IX.

SKETCHING WITHOUT INSTRUMENTS.

Any one who has practised plane table sketching will find no difficulty in employing the same system when totally unprovided with instruments, a condition of things very probable in the exigencies of active service.

The system of triangulating and of traversing independent of the compass, as already described (Secs. IV and VII), will have to be pursued, but the legs of the plane table will be dispensed with, and the sketch merely laid on the ground as level as possible. The lid of a box with the paper fastened on it, will answer the purpose as well as anything else. A straight-edged piece of wood must be used instead of the sighted ruler. A scale of equal parts, to represent hundreds of yards, may be drawn on the edge of a card for laying down the distances, the same scale being also drawn on the sketch. Its representative fraction may afterwards be found at any time that a foot rule or scale of inches is available (example, page 11).

The alignment of the ruler on the distant object may be effected by standing slightly behind the board on which it is laid, and holding the pencil near the eye in the same vertical plane as the distant point. Fig. 45.

FIG. 45.

Notice then whether the ruler corresponds also with the pencil, and alter its direction, if required, until it does so. This is both a more accurate and convenient method than endeavouring to look along the straight edge itself, which would necessitate kneeling or stooping. Greater accuracy may be obtained by using a piece of string instead of the pencil.

The ends of the base must be mutually visible from one another. Lay the board on the ground at one end of the base, and draw the lines with the ruler in the direction of the other, and of the various objects which are to be fixed by intersection. The point

on the paper from which these lines are drawn must be placed so that the sketch will contain the whole of the ground.

Now measure the base by pacing, and set it off to scale. At the other end lay the ruler on the line, and shift the whole board until the ruler is directed on the first point, thus "setting" it to correspond with the ground. Take up the ruler, direct it successively on the objects which were previously observed, and mark the points of intersection of the relative lines, determining their position. Care must be taken that the board remains unmoved during this process.

In traversing, the sketch is laid on the ground at any convenient station, which has been fixed as described, "set" by reference to another station, and the first traverse line drawn in the required direction with the ruler.

Before leaving the spot, all surrounding detail is drawn to scale.

After traversing up to the point where a change of direction has to be made, the board is "set" by reference to the starting point or line which has just been traversed; the next forward direction drawn, and so on, until the traverse can be "closed" on a convenient station, and a fresh departure taken.

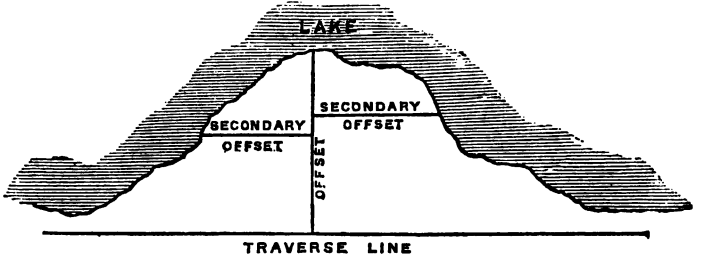
When distant points which have been fixed by triangulation are visible, the board should always be "set" by them instead of by the last traverse line, as just described. The edge of the ruler should be laid to correspond with the distant point on paper and the surveyor's place, and the board should then be turned so as to direct the ruler on the same distant point in the country.

The processes are precisely those described in reference to the plane table, but greater judgment must be used in arranging the work in the absence of a compass; this will especially be felt when it becomes necessary to sketch narrow lanes, or to follow a road through a wood, or in any ground when the view is restricted.

The principal rule to bear in mind in arranging the work is to make the operations as large as possible, that is to say, to use none but long traverse lines, and, if necessary, long offsets, in preference to changing the direction of the traverse line in order to sketch detail.

Secondary offsets will often have to be measured perpendicular to the principal offsets. Thus:

FIG. 46.

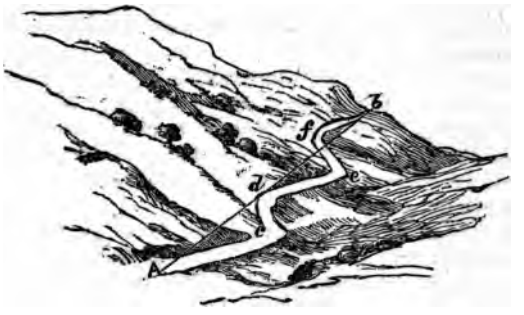


To sketch a road winding through cultivated ground; greater general accuracy would be obtained by traversing a line somewhat parallel to it across country, and finding the deviation of the road by offsets, than by attempting to traverse along the road itself. If the sun is shining, one may sometimes sketch detail in cramped ground by its help; before leaving the open ground

"set" the board by the known points as described, stick a pin firmly in it and draw a pencil line along the shadow. Then in deep lanes or woods one may "set" the board by placing it so that the shadow falls again on the line. This is of course not suited for accurate work, and will only be approximately true for a quarter of an hour or so after the shadow is first drawn.*

In rapid sketching of roads there may not be time to follow their sinuosities systematically, but by paying attention to the proper points, the general direction may be represented correctly enough. Thus:

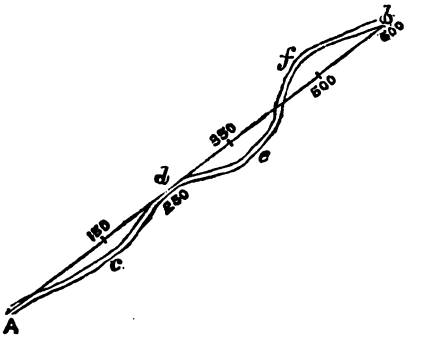
FIG. 47.



In looking along the winding road from A (Fig. 47), its general direction would be drawn towards the point *b*, where it disappears round the hill, and the windings estimated thus. *c* is judged 150 yards from A, and the length of an imaginary offset (or distance of the road to the right of the straight line) 20 yards; at *d*, estimated as 250 yards, the straight line would touch the road; *e*, 350 yards, is judged to be 30 yards to the right; *f*, judged 500 yards distant, and 30 to the left; *b*, 600 yards.

From these estimated data the road would be drawn in plan. Thus:

FIG. 48.



The deviations of the road appearing much greater than they really are.

* In India, where the continuance of sunshine may be depended on, it is customary to construct a small dial on the sketch, suitable to the time of year, showing the direction of the shadow of a vertical pin for every hour of the day. Then the surveyor can, by the aid of a watch, "set" the plane table during the progress of the work, by revolving it until the shadow falls in the direction marked on the dial as due to the hour.

The place may be found by interpolation, without instruments, as explained with the plane table, independent of the compass; but in practice these problems will seldom be employed, as requiring too much arrangement and time.

The accuracy to be obtained in properly managed sketching without instruments leaves nothing to be desired, but it is not so rapid as, and requires more forethought than, compass sketching.

The true north may be shown approximately by "setting" the sketch on the ground, and drawing a line coinciding with the shadow of a plumb-line at noon; the accuracy of this depends on the time of the year, the sun being generally within a few degrees of true south at noon, mean time.

In sketching hills, attention is to be chiefly paid to the position, slope, and direction of the watersheds and watercourses; these alone, if shown on the sketch, will give a fair idea of the configuration of the features.

Previous practice with instruments will have enabled the surveyor to judge the degree of slope at sight. A scale of horizontal equivalents should be drawn on the sketch, suitable to the proposed vertical interval (page 20), and the contours should be sketched by eye as nearly as possible at the equidistance appropriate to the slope, as shown on this scale.

After very little practice slopes can be judged correctly within 1°. The steeper the slope the more difficult to estimate correctly.

General remarks on Sketching.

A beginner can only perform one of the operations of sketching at a time, and is obliged to divide the performance of a sketch into separate operations; first, the measurement of base and fixing of stations by triangulation; next, traversing the roads and sketching the detail; and lastly, sketching the hill features. After some experience he can combine these operations, so that no part of the ground need be revisited.

On commencing a sketch, at a spot which commands an extensive view; the direction of a few prominent distant points, such as houses, groups of trees, &c., will be laid down, whether by compass or plane table; the names of these objects are written on their respective lines near the margin of the paper. Instead of measuring a base and intersecting these lines from the other end, the surveyor proceeds at once with the traversing (selecting his traverse lines with judgment so that they may be as long as possible). When he arrives at a spot whence a good intersection of one of the distant points can be obtained, he determines its position by observation and intersection.

Thus the operations of sketching the detail close at hand, and of fixing distant points, are carried on simultaneously by what may be termed a "running triangulation."

It will be seen that this system must be followed with great care and judgment, as there is no means of checking the accuracy of the work in its earlier stages, and any error will be carried on and pervade the sketch; in fact, it is only suitable for a person who does not make mistakes. If the earlier part of the sketch be carefully executed, a number of useful points are secured, by reference to which, later on, its accuracy can be checked.

Simultaneously with the execution of this running triangulation, the features of the ground must be studied and sketched. The ad-

vantage of the system of "reference points" is now found. Having, on first commencing the sketch, registered one or more of these, as described, the surveyor is enabled, by means of his clinometer, to place himself *on a contour* at any time, and to sketch the feature on which he may be, with the knowledge that its contours can be joined with truth to those of adjoining features.

Time may be so limited that all possible in the way of hill-sketching would be the indication, by a few touches, of the general position of the principal features. By means of these indications and a good memory, the surveyor should be able to produce a faithful representation of his recollection of the ground, its steepness being graphically expressed by contours placed according to the scale of slopes shown on the sketch. Should time admit, he can further develop the hill forms by lead and a piece of leather (a glove will do) in a few minutes.

When the sketch is to be finished out of doors, the detail and contours should be drawn with a very hard pencil before the shading is commenced; the latter can then be applied in the usual manner, without obliterating the drawing. The contours may be finally shown with a red pencil, if red ink or colour be not available.

Green or blue chalk scraped from a pencil can be used in the field in imitation of a flat wash of water-colour, rubbing it in with clean chamois leather in the same manner as the hill shading.

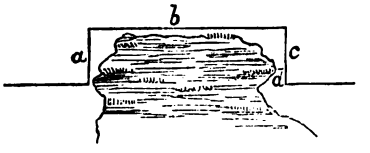
In case of rain the sketch should be carried face downwards and exposed as little as possible. India-rubber or eraser must on no account be used on wet paper; its saturation is of little consequence, as after being dried gradually, it recovers its texture; and the sketch, though having been apparently hopelessly destroyed, can be finished up as if it had never been wet.

In traversing across undulating ground, one is liable to lose sight of the point on which one is pacing, when descending into hollows of the ground. Foreseeing this, it is necessary to look for some object, such as a tuft of grass, or a bush, *on the alignment*, so situated that it will remain in view, whereby to preserve the direction of the traverse line.

When a traverse line crosses a stream, deep railway cutting, nullah, or anything narrow that interferes with measurement, the distance to the further side should be *judged*, and the pacing resumed there; this is better than attempting to measure it by pacing.

Much depends on the true estimation of a perpendicular. When an obstacle, such as gorze or marsh, occurs on the traverse line or base, the best way of avoiding it, is to measure a perpendicular offset *a*, so

FIG. 49.



as to clear the obstacle; continue the measurement on *b*, perpendicular to *a* (that is, parallel to the traverse line), until the obstacle is passed; then return to the line by another perpendicular *c*, equal to *a*, and resume the pacing at *d*.

Examples.

(1.)

A stream rises in the centre of the sketch and flows for 525 yards

in the direction 250° 30′; here it joins the sea. The fall of the stream is uniformly 1 in 20.

The general direction of the sea coast is north and south.

From the source of the stream the bearings of two hills A and B are observed 354° and 207° 30′; from the mouth of the stream A bears 42°, B, 98°.

A is 150 feet above the sea.

At B the angle of depression to the mouth of the stream was observed 5°.

Sketch the ground. Scale, 12 inches to a mile. Contours, 10 feet intervals.

(2.)

An island contains three hills, A, B, and C. From the top of A the angle of elevation of B is 2°, bearing 179°, distance 780 yards. The angle of depression of the col which connects A and B is 3°; its distance from A 300 yards.

Interpolate the position of C. The bearing of A being 75°, of B 138°. At C the angle of elevation of A is observed 4°.

The sea is 200 yards west of C, and 65 feet below it.

„ 320 yards north and 370 east of A.

„ 260 „ south and 450 east of B.

Draw the island in contours at 20 feet vertical interval. Scale, 6 inches to a mile.

(3.)

Lay down the following triangulation:—Scale, $\frac{1}{7920}$. Base, AB 790 yards long.

At A, bearing of	B, 358°	At D bearing of	E, 346° 30′.
„ „	C, 304°	At C „	G, 345°
„ „	D, 59°	„ „	F, 197°
„ „	F, 250°		
At B, bearing of	C, 239°	Interpolate X.	
„ „	G, 287° 30′	bearing of	G, 28°
„ „	E, 64° 45′	„	C, 103°
„ „	D, 126° 30′		

The points G, X, F, A, D, are on the coast line.

C, B, E are the summits of hills respectively, 115, 135, and 154 feet above the sea.

D is a point on a cliff, 40 feet high.

The lowest part of the ground on the line CB is 45 feet; here a stream commences, which flows into the sea at A.

The lowest part of the ground on the line BE is 106 feet. Sketch the ground in 12 feet contours.

(4.)

Draw the following:—Scale, 5 feet to a mile; contours, 4 feet. A railway cutting, length 120 yards; width of roadway 15 yards; gradient of the line, 1 in 30.

Slope of one side of the cutting 15°, its top 20 feet above the line.

The gradient of the other side 1 in 6, its height 25 feet.

What is the width of the cutting?

SECTION X.

READING CONTOURED PLANS.

When the altitudes are figured in a contoured plan, no misconception can arise as to the meaning in any part; otherwise it is by the existence of water that one is guided in distinguishing between watersheds and watercourses in such features as those in Plate IV.

Therefore, the lowest part of the country represented should first be recognised, usually occupied by the largest body of running water (the W). Then the tributary streams, U, Y, are traced upwards. Also the watercourses V, R, H, where the contours take a re-entering bend.

Next, the watersheds occupying the ground between the watercourses, here the contours take a salient or outward bend. The features which it is most important to recognise on watersheds are the cols which show the connection of features with each other, D, L, M, S, Q.

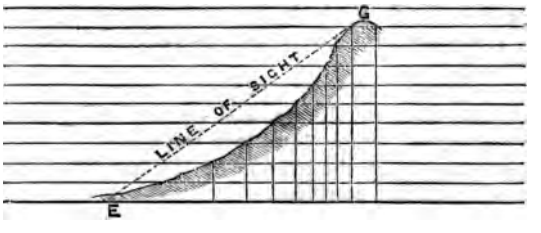
In comparing the relative heights of hills, either count the contours from the col which connects them—for instance, G is three contours more than P above the col M—or if more convenient, count the numbers from the intervening watercourse. Thus, A is three contours more than G above the watercourse HH.

The number is of course not the number of *contour lines*, but of *intervals* between them, so that the first contour must be called O, not I.

The difference of level is found by multiplying the vertical interval between the contours by their number. Thus, supposing the contours in the diagram to be 20 feet vertical, A will be 60 feet above G and 240 feet above E.

To determine whether a point is visible from another point, as G from E. If a section on this line be drawn, it will be seen that these

FIG. 50.



points are mutually visible, *because the general section of the ground between them is concave.* But this fact can be recognised on the plan at a glance, because the contours are closer at the top than at the bottom of the hill. By the same reasoning, when the contours are closer at the bottom of a slope than at the top, as in the line KI, the section of the ground must be generally convex, and the points mutually invisible from one another.

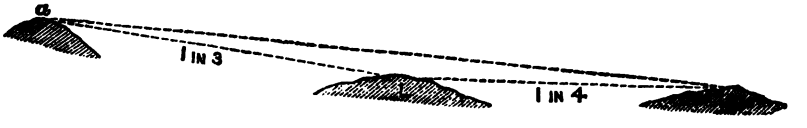
A question of the visibility of points from one another then resolves itself into one of the general concavity or convexity of the intervening ground. This can of course be determined by drawing a section, but there should be no necessity for employing so clumsy a process, the question can be settled by inspection of the plan in most cases.

The opposite sides of hills, separated by a valley as G and A, or P and N, are mutually visible each from each, but when another hill intervenes (as P in the line NO) the consideration is, whether its elevation is sufficient to intercept the line of sight, or in other words, to make the section convex.

On examining the plan it is seen that O and P are the same height, but N is three contours below P, so that the general form of the section must be convex. Hence it is seen that troops might march from village B by the cross roads near O, and across the intervening valley as far as P, without being visible from N.

Ex. I. Could a battery at *a* (near A) bring fire to bear on N. Joining these points by a line, it is seen that the ground about the col L might intercept the view. But this is only one contour higher than N in about 4 inches on the plan, whilst *a* is eight contours above the col in about 3 inches, or nearly three contours in 1 inch. Hence *a*L is steeper than LN, and the section concave, so that N would be within view. The solution of a question of this sort can usually be arrived

FIG. 51.



at by estimating the distances in inches, and counting the contours as above, though problems may occur requiring more exact measurement.

Ex. II. Would the churchyard, village Z, be under fire of a battery at G. The point *p* is in question, as likely to intervene.

The slope G*p* is 4 contours in about 4 inches, or 1 in 1.

p to the church is 5 contours in about 2 inches, or more than 2 in 1.

Hence the section is convex, and the churchyard not under direct fire.

FIG. 52.

Ex. III. Could a picquet be posted in the fields immediately east of N, unseen by an enemy's vedette at G.

The ground *nn* east of N falls about 1 contour in half an inch. GN falls 6 contours in about 5 inches; less steep than *nn*. Therefore the picquet would be unseen.

In the foregoing examples of deciding on the mere visibility of points, neither the scale of the plan nor the vertical interval between

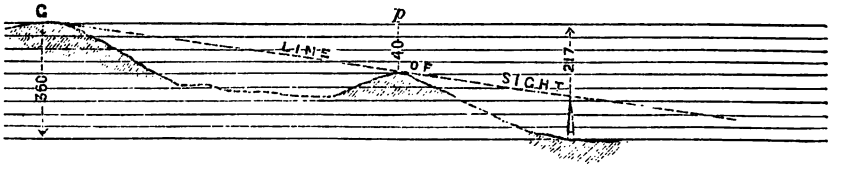
the contours need be taken into consideration. But these form the basis of calculation in determination of actual heights.

Ex. IV. For example, supposing the weathercock of Z church to be just visible from G, what is the height of the church? Supposing the scale of the plan, 4 inches to a mile, and the contours 40 feet vertical interval. The slope G*p* is 4 contours, or 160 feet, in 1120 yards. The distance from G to the church is 1524 yards, therefore the weathercock is below G. 1120 : 1520 :: 160 : 217 feet.

The base of the church is below G nearly 9 contours, or 360 feet.

The difference between these is the height of the church, 143 feet.

FIG. 53.



Ex. V. The enemy's outposts occupy the whole of the ground east of river U. It is required to march a picquet from the south by the road X, to occupy the farm at L unobserved. At what point would it be necessary to leave the road, and what would be the best route thence to L?

Examination of the plan will show that the first place where the road would become visible is about *x*, and that there is only one spot T in the enemy's possession, whence this can be seen.

Leave the road a little to the south of *x*, and keep to the west of the knolls at O.

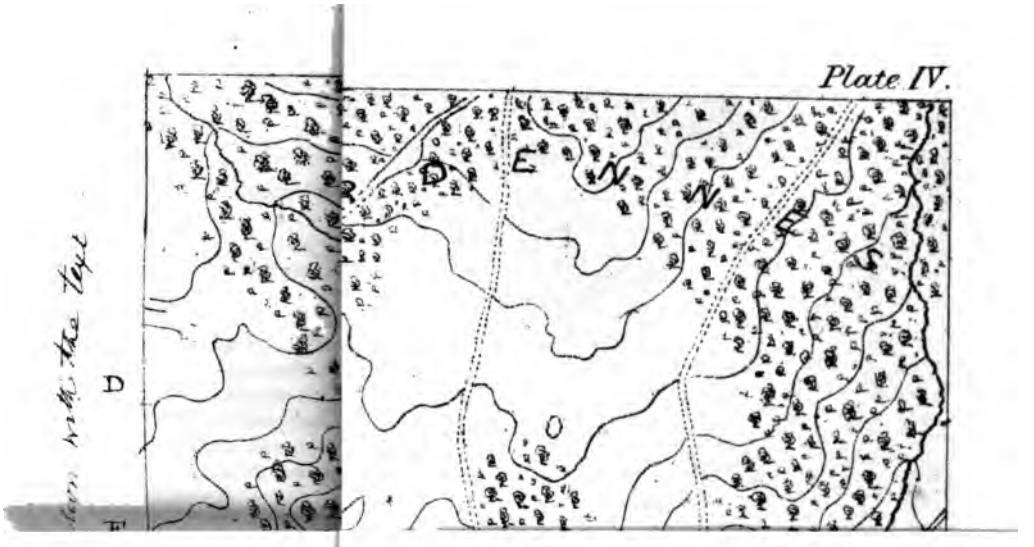
The northern slopes of G must be visible to the enemy over the col L. Therefore it would be necessary to move direct towards H, whence the road leading towards L might be followed.

In the preceding cases it is assumed that the contours are strictly accurate. No certain deductions could of course be drawn from mere sketches having no pretensions to a high degree of accuracy. In the new English Ordnance Survey maps, the contours shown at 100 feet intervals, though perfectly accurate, are not close enough for tactical guidance, the distribution of outposts, &c. Nor would the civil maps of any country serve as perfect military plans in this respect, however suitable for strategical purposes.

Questions with reference to Plate IV.

1. Plan scale, $\frac{1}{10000}$, 25 feet contours. State the steepest gradient of the road between X and *x*.
2. The plan scale being 5 inches to a mile, and the contours being placed according to the normal scale of slopes.
   (*a.*) What is the difference of level between A and N?
   (*b.*) State the angle of depression of N below A.
3. Would any part of the road between the villages of C and Z be visible from K?
4. Can the whole or any part of the road X*x* be seen from A?
5. Would a person walking in a straight line towards P, from the farm in the S.E. corner of the plan, be within view of the former point throughout?

Plate IV.



6. The outposts of an army which is operating north of the plan are posted in the skirts of the Forest of Ardennes. The enemy south of the river W is expected to move northwards by the roads shown.

   Two vedettes are to be posted in observation of these roads, and within view of each other. Not to advance farther than half a mile from the forest.

   Plan scale, 4 inches to a mile.

   Indicate suitable posts for them.

7. What horizon is visible from N, and how could troops be moved from the south to the north within the limits of the plan, without being seen by an observer at N?

SECTION XI.

RECONNAISSANCE.

Reconnaissance is the process of obtaining and recording information concerning the movements, number, and disposition of an enemy; the nature and resources of the country, especially its communications or facilities for the movement of troops. In fact, everything that affects the combinations which a general may seek to carry out. Knowledge of his intentions and of the necessities of the troops indicate the points which should be made prominent in any reconnaissance.

As a rule, the outpost and cavalry duty of an enemy is so vigilantly performed, that there will be no possibility, when in his immediate vicinity, of observing anything of his dispositions, short of making an attack in sufficient force to thrust back his outposts and oblige him to reveal his strength. Details concerning such "reconnaissances in force" would be foreign to the present subject.

Specially appointed officers will be always on the alert to avail themselves of any opportunity of gaining intelligence, and such officers must possess clear judgment, presence of mind, experience, readiness of hand, and good memory. Rapidity and accuracy in sketching and taking notes are indispensable; in warfare there will be a consciousness of liability to surprise by the enemy's light cavalry, even though his main body may not be within several days' march; that will suggest the necessity of speed combined with coolness and judgment.

Under such circumstances the work will usually be done in the saddle; for instruction the beginner will have to sketch on foot until he has acquired facility of execution and knowledge of the points to which he should direct his attention.

Every officer should be able to give clear information by sketch and report concerning the ground in the vicinity of his outpost, as a guide to the posting of picquets, movements of patrols, &c. Also to execute a sketch of 10 or 12 miles of road in anticipation of a march to take place the following day.

To sketch quickly and accurately it is necessary to be a good judge both of distance and direction, also to be accustomed to the representation of objects in plan. To report intelligently requires some knowledge of the practical application of field fortification; ability to recognise the points which constitute defensibility in villages, farmsteads, or other posts: acquaintance also with the capabilities of the three arms, their rate of march, and the space they will occupy in route, and in camp, or bivouac.

If the officer can speak the language of the country, so much the better, otherwise he must be hampered with an interpreter. Under any circumstances, much of the information must be obtained by questioning; and great tact, good humour and firmness are required in this. It may be even necessary in a hostile country to resort to

intimidation, but little dependence is to be placed on intelligence so extorted. The inhabitants would naturally endeavour to mislead the reconnoitring officer; they would assert that the roads in the vicinity of their village were impracticable, to prevent troops being billeted upon them; conceal the existence of fords in a neighbouring river, and exaggerate the difficulties of the surrounding country.

Names of places should be written phonetically as pronounced by the inhabitants, in addition to their spelling as given in the maps of the country.

Complete information as to any locality can only be given partly by written description and partly by a sketch. The rule in compiling these is, that the same information should not be repeated or given in both, but each should be the supplement of the other. The superior officer must not be called upon to read unnecessary or irrelevant matter. Very legible writing is essential; for on service these reports would often have to be read at night, and perhaps by the light of a stable lamp.

Investigations and reports should be governed solely by the object with which the reconnaissance is undertaken, so that information relevant in one case may be superfluous and useless in another. For instance, in following up a retiring enemy, information as to positions for an advanced guard would be useless.

Or an officer charged with reporting on the facilities for making an immediate advance by a column provided with cooked rations, would not be thanked for sending in a return of the number of sheep, oxen, &c., to be found in the farms adjoining the road, though in this case watering places should be reported on.

On the other hand, the supplies to be drawn from a district might be one of the chief considerations, when a large force is moving through it.

The headings in the authorised form of report will therefore be filled up or left blank as the circumstances of the case may require.

The reconnaissance of roads is more frequently made with a view to the movement than to the maintenance of troops, and therefore tactical rather than statistical information is required. With this object two forms of report are adopted, the second (for supplies and statistics) only to be filled up and attached to the other when such information is specially called for.

In framing reports, the ability and judgment of an officer are shown as much in what he omits as in what he writes. It requires more thought and care to compose terse and well condensed, than lengthy diffuse reports.

The existing maps of the country are sufficient guide to the general dispositions for a campaign, concentration of troops, and other strategical combinations; but further and more particular information than these can furnish is required for the minor operations of war. A sign-post, a heap of stones, &c., may be important indications by which to describe the identity of a cross road; a slight and unnoticed fold of the ground may give cover to a battalion.

The Sketch.

Road and river sketches are usually executed at the scale of 2 or 3 inches to a mile; positions 4 to 6 inches to a mile.

The sketch should contain as much as can be shown without con-

rusing or overcrowding it. Remarks should usually be made in the margin, clear of the sketch, and connected with the object to which they refer by a light line, as shown in the example.

The sketch of a road will be commenced at the bottom of the paper, and carried upwards in the order of the march. Where (as will generally be the case) the sketch takes the form of a long narrow strip, the meridian lines must be arranged diagonally on the paper, if necessary, so that the road may occupy the centre of the sketch sheet, and that no cutting and piecing of it shall be required to fit the sketch together.

The minimum of drawing is to be done in the field; a single line will be sufficient to show the road, the sketch may be afterwards finished up as highly as time will permit. A red and blue chalk pencil will be found very useful to distinguish houses and water in the field. An officer who has been accustomed to sketching at the usual large scales, will on commencing sketching at 2 or 3 inches to a mile, lose time in trying to represent too much. At such small scales very little detail can be shown, every house in a town or village cannot be drawn; it is only necessary to distinguish such buildings as manufactories, jails, or churches, to show the side streets correctly, and afterwards to fill up the intervals with the conventional sign for buildings.

In a closely fenced country like England, it is allowable to generalise details of fences in the less important parts of a road, and merely to represent enclosed fields of the average size according to scale. In sketching ground likely to be defensively occupied however, the fences must be surveyed with accuracy.

Lines may be drawn in the direction of important places some miles distant; the names of the places being written on these lines, their position and distance may be known by judging where the point of intersection would occur (*vide* Plate VI).

The surveyor seldom leaves the main road, except it be to follow a cross road for a short distance in order to examine a bridge or ford by which it passes a stream. As much of the country on either side as is visible from the road itself (generally about half a mile) is sketched.

Distant buildings, woods, &c., are placed in the sketch by estimating their distance as soon as they are perpendicular to the traverse line.

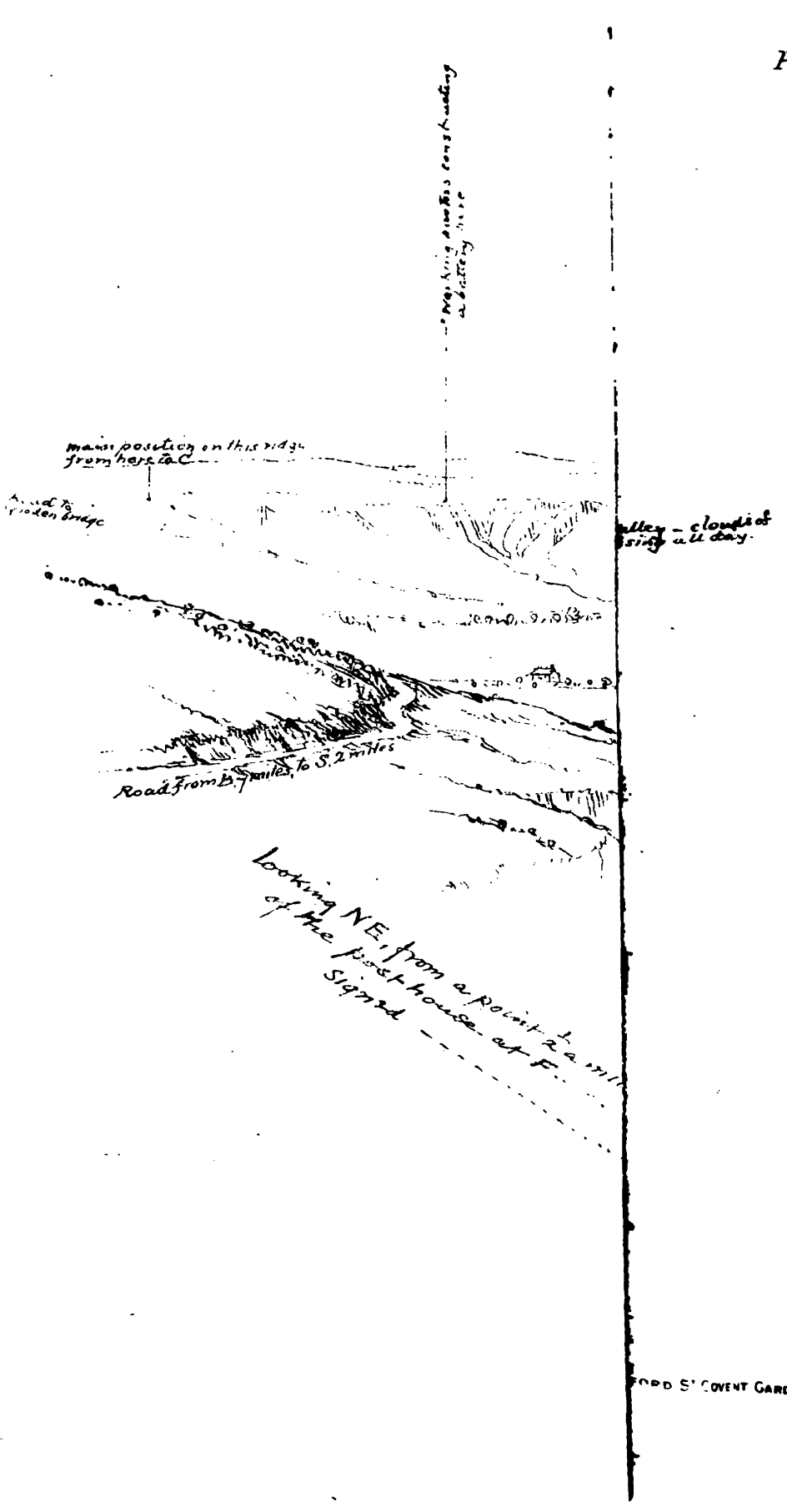
The general direction of transverse roads is usually merely referred to that of the traverse line; but when the direction of such a road can be seen for a considerable distance (half a mile or so), it should be observed with the compass.

In sketching a winding road, it will generally be sufficient to take the bearing of the longer reaches, and to draw the direction of the intermediate portions by eye. If the cavalry sketching case be used, the direction is so quickly observed, that every bend in the road may be laid down by compass.

Attention must not only be paid to that which is near, the general lie of the country must be noticed. The position of streams may be known by the willows, &c., growing on the banks; the direction of the flow of surface water through culverts, shown by the lie of weeds at the bottom, will be mentally noted as an indication of the general fall of the ground when nearly level.

In representing hills at such small scales as 2 or 3 inches to a mile, it will be convenient to use a scale of slopes somewhat closer than the normal scale (page 21).

Plate V.


main position on this ridge from here to C
Road to Wooden Bridge
Road from B. 7 miles, to S. 2 miles
looking N.E. from a point 1 a mile of the post house at F.
Signed

FORD ST COVENT GARDEN 3092

Roads cannot be represented of their proper width at such small scales, but should be drawn as narrow as possible.

It would be unnecessary to attempt showing contours at levels common to the whole of the ground. No great accuracy is required in the representation of the minor features, and it will be sufficient if a correct idea of the general form and position of the *important* features be given by contours which need not be produced to meet those which represent adjacent features.

The scale of slopes should be drawn on the sketch to guide the eye in placing contours at the distance due to the estimated slope.

When sketching roads, a mounted officer will measure distances by counting the paces of his horse, the average length of these paces having been previously found by experiment over a measured distance of 300 or 400 yards, or between two milestones. In trotting, the number of times the rider rises in the saddle should be counted. Scales suitable to the horse's paces should be drawn on the edge of a card for use in the field, or marked off on the edge of the ruler of the cavalry sketching case. They should also be marked on the sketch itself, so that a fresh scale may be prepared in case of losing the original. A scale of yards is also required for laying off estimated or paced distances.

The Government maps of any civilised country will be found most useful as a general guide to the route which is to be reconnoitred; but these being on a small scale, cannot show the distinction between roads of different constructions and widths; nor their present condition as affected by the season and the passage of armies; the passability of fords; recent alterations, and so forth.

Should there be occasion to illustrate the description of any object of great importance, a small freehand sketch may be made in the margin of the survey opposite the place. Such a drawing might be made, for instance, of a cart shed on the road side, where a footpath leads to a ford or foot bridge. This drawing might enable the point to be recognised at once, when its identification by means of the plan might cause delay. Or the distant view of a remarkable clump of trees or church spire might assist the superior officer in recognising the locality on his arrival. On no account should objects be sketched because of their pictorial effectiveness, or merely to show the skill of the draughtsman; there should always be good reason for adding them to the survey.

A landscape sketch is often the only means by which the appearance of the enemy's position can be represented, as for instance when an officer succeeds in getting within view of it, but cannot attempt instrumental observations or measurements of any kind. In these sketches prominence should be given to objects which are likely to play an important part in the attack or defence of the position: villages, farms, roads, artillery positions, streams. The sketch should be as much as possible in outline, and nothing should be exaggerated or misplaced (Plate V).

The point of the compass from whence any landscape sketch of an object was taken should be stated, also the distance.

Should there be no room in the margin of the survey, the drawing may be attached to its edge, opposite the place.

When there is time to clean and finish the sketch before handing it in, it is advisable to ink it, because then it can be cleaned up as it is drawn, without the danger of obliterating any detail. Finishing in pencil requires more care on this account.

The rate of working will vary according to the nature of the country. In general an experienced sketcher can do 1½ to 2 miles an hour on foot, or 3 on horseback. The chief advantages he derives from being mounted (apart from considerations of security when on active service) are that he can see over hedges, &c., and obtain a much better idea of the surrounding country. He will not hesitate to trot down side roads occasionally, gain information as to railways, rivers, positions, &c., and gallop back to the main road. On foot he would probably have time only to sketch the main road and what he can see from it. He has the means of returning to camp and handing in his sketch, of perhaps 10 or 12 miles of road, the same evening. Details as to sketching on horseback will be found further on.

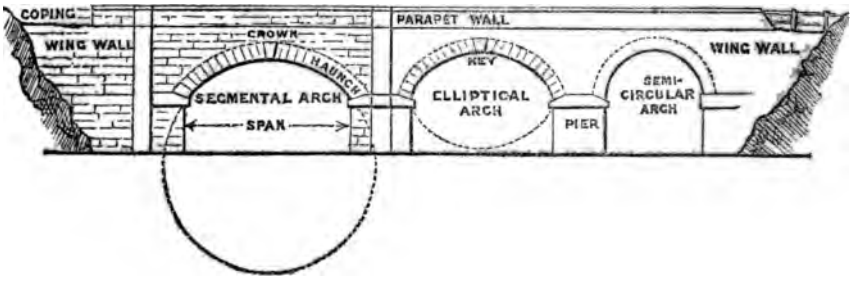
Information as to Roads to be given under the different headings.

1. The roadway, metalled or not. Width of metalled portion. Metal or material for repairs, where available. Present condition, whether level or hilly, the steepest gradients to be stated in the latter case. Details as to any part that constitutes a defile, such as hollow ways or village streets. Nature of the fences by which bounded.

2. The bridges over which the road passes to be minutely described; whether strong enough to bear guns. Material, whether of brick, stone, iron, or wood. Breadth and length of the bridge. Number of arches and their form; span. Height of roadway above the water. Thickness of piers. When there is no time for accurate measurement, the dimensions may be taken by pacing and estimation. Measurements may be written thus: feet, as 14′; inches, as 30″. Fords alongside the bridge.

The various parts of bridges are to be described by their correct names.

FIG. 54.



Iron bridges, length, breadth, height. Whether piers and abutments are of masonry or iron. Girders, whether lattice or wrought, or cast iron.

3. Anything that may tend to retard the usual rate of marching, such as the steepness of mountain roads, broken places, rocky passes, deep mire, heavy sand. In every case the probable rate of marching to be given.

4. Towns and villages. Material of the houses, inflammable or otherwise. Whether the streets are paved or not. Defensibility. If commanded from neighbouring heights. Materials for barricading

and for making abattis. Whether entrenching tools are available in any quantity. Name the principal large buildings, such as the church, townhall, exchange, &c., suitable for use as temporary barracks, hospitals, or magazines; also whether they are capable of defence, and how they are situated with reference to the approaches to the town (if this point is not clearly shown by the sketch).

5. Water to be found near the road fit for drinking, or for watering horses.

Whether there are conveniences for watering a number of horses at a time.

6. The country. Whether the ground is rough and broken, or the contrary. Whether marshy or dry, wooded or open. The general nature of the fences, whether banks, walls, hedges, &c. Character of the cultivation, whether the view is generally much restricted by hedge timber and woods. Whether movement across country or parallel to the road would be possible for the different arms; the nature of woods near the road, whether impassable on account of underwood, or open.*

7. Rivers. Breadth, depth, rapidity (so many miles per hour). Nature of the banks and bottom. Command of one bank over the other (if any). Fords.

8. Halting places and shunting places, where part of the column could pass from the rear to the front.

9. Camping grounds, or bivouac ground. Force for which available (if required by the nature of the instructions).

10. Positions on, or adjacent to the road, for advanced or rear guards (according to the instructions). Also positions commanding the route from the enemy's side, or from whence he could observe the march; these to be reported on as seen from the road.

11. Lateral communications, roads, or tracks crossing or joining the road, their construction, width, and condition.

12. Railways, broad or narrow gauge, single or double line. Stores and rolling stock available (if required by the nature of the instructions).

In reporting on bridges, the culverts need not be described in detail, it will be sufficient to show these on the sketch. The distinction between culverts and bridges cannot be exactly defined; the details should be given concerning those the demolition of which would entail delay and require special material, bridging spars, &c., for their reconstruction. Material such as beams from the roofs of the nearest buildings, can be obtained anywhere for the repair of culverts and bridges of small span, 6 feet or so, and it would seldom be considered worth while to destroy these.

Camping Grounds.—A battalion of infantry requires a minimum space of 64 yards front, 200 yards depth. This is too crowded for any but a passing encampment, and allows for no parade ground in front. A full sized camp for a battalion should be 400 yards front, 276 yards depth.

A regiment of cavalry, minimum 68 yards front, 180 yards depth. A battery of field artillery, minimum 72 yards front, 100 yards depth.

To find the Rapidity of a Stream.—Place two marks on the bank, about 50 yards apart. Throw into midstream some object which will rise as little as possible above the surface. A small branch answers the purpose well, as its twigs reach down some distance. Observe

* In the case of high crops, such as hops or vines, the direction of the rows is often important.

the number of seconds it takes to pass from one mark to the other; from this may be calculated the number of yards per minute, or miles per hour.

The fordability of rivers depends, 1st, on the depth; 2nd, on the rapidity; 3rd, on the nature of the bottom. The two latter being favourable, a ford 4 feet 3 inches is practicable for cavalry, 3 feet 3 inches for infantry, 2 feet 6 inches for artillery.*

The Gradient of Roads.—Heavy wagons cannot ascend a steeper slope than 8°, or 1 in 7, without extra horses; but guns can for a short distance be taken up 15°, or 1 in 4.

The Report.

Before commencing to write the report, every place in the survey to which allusion will be made in it, should be marked with a red numeral surrounded by a circle, consecutively, from the bottom of the sketch upwards for the purpose of identification. This is better than numbering them whilst writing the report, for it would be then found nearly impossible to arrange the consecutiveness of the numbers *on the sketch* which is so convenient to the superior officer.

Places, the names of which are given on the sketch, need not be also numbered.

The terms north, south, &c., not "right" and "left," should be used in describing a position. The former are absolute, the latter being relative, there might be room for doubt whose right or left is meant, the enemy's or our own.

In describing a river, however, the terms "right bank," "left bank," are made use of, with the understanding that the observer faces towards the mouth of the river; this is necessary, as either bank might become north or south, east or west, on account of the windings of the stream.

The sketch as well as the report should be headed, signed, and dated by the officer on the face of each document, so that they may be rejoined correctly in case they should become detached.

The instructions in accordance with which the reconnaissance was made are to be attached as the last sheet of the report.

When the length of the sketch sheet is different to that of the foolscap paper sized form of report, the lower edges of each are to be in line, the sketch attached to the left margin of the report by loose loops of tape or twine, or by a strip of gummed paper applied to the edges at the back. Postage-stamp edges, or adhesive luggage labels cut in strips, answer the purpose.

The form of road report will be folded as shown Plate VI, so that the marginal headings may be seen in their proper places when the report is turned over for the perusal of the third column.

The first column of the report will usually be large enough to contain all the information concerning one march.

When intelligence is obtained by hearsay its source should be stated, in order that a judgment may be formed of the degree of credit to which it is entitled.

When statistical information concerning supplies, accommodation, &c., is required, an officer will usually be detailed to collect and tabulate it in the authorised form, independently of the officer who

* For examining fords, *vide* "River Reports."

sketches the route and studies its tactical capabilities. In this case he must be careful to use the same reference numbers as are marked in the sketch to identify places.

For purposes of instruction, time being of little consequence, both kinds of information might be furnished by the same officer.

Supplies and Accommodation.

The column "distance" may be left blank when the report is accompanied by a sketch, otherwise this information is necessary.

The order of reference numbers should be similar to that in the sketch, that is to say, the most distant place is first described at the top of the fair copy of the report, the remainder in regular succession, the starting point coming last.

The number of houses and the population of towns and villages can generally be obtained from the local authorities; it is usual to estimate a village population at about five per house. No absolute rule can be laid down for the proportion which "accommodation" is to bear to the population; the relation must necessarily vary considerably according to circumstances. It will be sufficiently accurate to calculate as follows:—

For every room 15 feet wide or under, one man to every yard in length.

For rooms over 15 feet, but under 25 feet in width, two men for every yard of length.

For rooms 25 feet wide three men for every yard of length.

This allowance of space would be insufficient for permanent occupation.

The late Major-General Sir G. P. Colley recommended the following as a useful method of roughly estimating the accommodation:—Pace along the front of the building or buildings: if only one room deep, calculate one man per yard; if two rooms deep, 2 men per yard, and multiply by the stories.

As it will be impossible for an officer to visit every house in a town or village, the best plan to adopt will be to divide the houses into classes as far as possible, and by carefully examining a house of each class, and estimating the number of men which it would accommodate, arrive at a fair estimate of the accommodation afforded by the total number of houses. A certain number of rooms (usually those on the upper storey) must be left for the inhabitants.

As regards horse accommodation in barns or outhouses, about 5 feet of their length should be allotted to each horse. If the building is 24 feet wide it will hold two rows of horses with a passage of 6 feet or so between them.

In India no information is required concerning the accommodation to be obtained in villages, as they are unsuitable for occupation by Europeans.

Under the head of "supplies" is stated the names of the principal persons upon whom requisitions for flour, corn, hay, oats, and live stock might be made, stating the amount obtainable from each person. Butchers', bakers', and blacksmiths' shops; fuel and corn stores; hotels and inns; postal telegraph, and number of clerks; forges, mills, and wheelwrights.

For calculating the supply of fodder:—Hay weighs 200 lbs. per

cubic yard in the rick; straw, 140 lbs.; grain, 900 to 1,300 lbs. per cubic yard; oats are the lightest.

Under the head of "transport" will be given the names of those persons who possess carts or wagons adapted to the transport of commissariat and other stores, with the number of horses belonging to them. Also the names of persons on whom requisition can be made for saddle horses.

Under the head of "water." Whence is the water supply available? Is the supply limited? Is the water of good quality?

To find the supply of cubic feet of running water per minute. Calculate the area of the cross section of the stream in feet (breadth × average depth); multiply by velocity per foot per minute.

To find the supply in gallons, multiply by 6·23. Ten gallons allowed for each man and horse per day.

A specimen of a road reconnaissance in the authorised form is shown, Plate VI, in a pocket at the end of the book, the manner in which it is folded is to be observed; it was executed in accordance with the following instructions:—

General Idea.

An army corps is retiring by divisions westwards, on parallel roads, followed by a superior force. The 2nd Division, marches by the Becton-Hilboro Road, covered by a rear guard, comprising—

2 squadrons cavalry,
1 battalion infantry, 800 strong, with tool cart,
2 guns horse artillery,
4 guns field artillery,
1 company R.E., with tools on pack horses.

An officer is to be detailed from each infantry regiment to precede the column by one day, to report upon the route and collect such information as may be required.

Instructions communicated to Officers concerned.

Captain A. will report to-morrow on the section of the road from Carbury Station to Appleton. He will render his report to the D.A.Q.M.G. at Carbury Station at 7 P.M., 17th Sept., 18 .

Information is required as to—

The condition of the road and its suitability for rapid marching.

Facilities for maintaining communication with the 1st and 3rd Divisions on roads to the right and left.

Facilities for moving on a broad front.

Any position in which the rear guard might delay the enemy's advance and oblige him to deploy.

A suitable halting place, about half way if possible, for the mid-day meal. Three days' rations are carried with the column.

Lieutenant B. will act in conjunction with Captain A. in reporting as to the supplies to be obtained at Heysthorpe and Llanyrll.

It is intended to reach Hilboro if possible and there bivouac on the night of the 18th Sept., so that no information is required as to camping grounds in this section.

River Reports and Sketches.

The sketch of a river must usually be made on foot. It is generally executed at the scale of 2 or 3 inches to a mile.

Rivers influence the operations of a campaign materially. If in front, and perpendicular to the line of advance, it is necessary to concentrate for the passage of a river at one or more points, and to deceive the enemy as to one's real intentions. With a large river close behind him a commander is placed in a position where an unsuccessful action should mean ruin, unless he has made preparations on a large scale like Napoleon's at Lobau. A river parallel to the line of advance is the best protection from an enemy's enterprise on a flank, as it is only necessary to seize the boats and guard the bridges in order to secure it. In any case a thorough knowledge of its nature and present state is essential to a commander.

The sketch will include as much of the country as can be seen from the banks, especial attention being paid to the villages and woods close to it, the roads leading to it, and all commanding ground within artillery range.

The following headings comprise the information generally required:—

A.

When the course of the river is in the direction of the line of operations, the object of the report being to show how connection may be maintained on the march, or for action, by a force moving on both banks.

1. General nature of the valley in which the river lies: whether swampy, rocky, wooded, &c., proximity of heights on one or both flanks. As much as possible of this information to be given *on the sketch*.

2. Nature of the stream, navigable or otherwise, and if affected by the action of the tide. Breadth, average depth, rate of current, liability to sudden overflows, and to what extent is the country usually flooded. Character of the bottom.

3. The banks: whether precipitous, and if so, how high? If one bank commands the other. Are the banks marshy or the reverse? Towpaths.

4. Tributaries. Islands.

5. Bridges in full detail. Fords and their approaches, ordinary depth, the bottom soft or firm.

6. Other points at which passages of the stream are practicable, or might be made so, for the different arms.

7. Boats.

8. The position of the locks being shown on the sketch, what is the fall of water at each? Are the lock gates exposed to distant artillery fire?

B.

In addition to the above. When the river is to be used as a defensive obstacle.

9. Nature of the approaches, and points at which access by them may be barred by troops or obstacles.

10. Command, and distance from the stream of heights on either bank within artillery range.

11. Points and means for effecting inundations.

12. Points on either bank suitable for covering the passage of troops to the further bank.

The arrangements for attaching the report to the sketch will be the same as shown for road reconnaissances (Plate VI). The headings in the above order will be margined in the same manner.

The strongest current will almost always be in the centre of the river. In winding rivers the deepest part will be found near the concave bank. A fall of 6 inches in a mile will produce a current of 3 miles an hour in a large, deep river.

The most certain way to search for fords is to drop down the stream in a boat with a sounding lead or weight attached to a line of the required length; the movement of the line will show when the weight touches the bottom, and a ford may there be looked for. Fords seldom run straight across the stream, but more usually in an oblique direction. In India, quicksands do not generally occur in running water, but on the flat banks. A post should be set up in the water showing its height at the time it was examined.

In describing flying bridges and ferries, the number of men that can be carried over in each trip, and the time occupied in making the passage, should be stated.

Any work on tactics explains the points which are favourable for forcing or defending the passage of a river. The reconnoitring officer will pay particular attention to these points, and examine thickets, woods, villages, &c., which would afford concealment or protection on the banks of the river.

If the operation is in progress in winter, it must be ascertained whether the river ever freezes; ice 3 inches thick will bear infantry and field artillery. The thickness of ice can easily be increased by covering it with straw and pouring water upon it during frost.

A navigable river with locks can be drained and made passable between two of these if the lower can be opened.

Railroads.

Railroads play an important part in modern warfare; by their means troops and matériel are transported with the utmost rapidity from one point to another, and a railway junction becomes an important strategic point.

In the reconnaissance of railways the following are the main points to which attention is to be directed:—

The general nature of the country through which the line runs.

The gauge in feet and inches; whether double or single line of rails; description of rail used, and how laid down and fastened; whether the sleepers are laid transversely or longitudinally; general description of bridges, of what material, the number of arches, the span of the arch, the best method of destroying the bridge.

The stations, whether large or small, of what material they are built, and whether they are adapted for defence; goods' sheds and other buildings; situation of the station, on the level, on an embankment, or in a cutting. The number of cross-over lines; the length and breadth of the platform; whether there are facilities for erecting temporary platforms. The sidings, if convenient for entraining and detraining troops. The means for providing engines with water. The supply of drinking water.

The entrances to the station, their width. The approaches to the station; space for forming up troops outside; space for encamping in the vicinity.

Amount of rolling stock; engines and their horse-power; carriages of each class, horse boxes, cattle-trucks, and goods trucks.

Places along the line where troops could be entrained besides the stations.

Stores of telegraph wire, spare rails, and sleepers; fuel; excavators' tools; forges.

The staff of railway officials, engine drivers, and pointsmen.

The number of telegraph wires; places where there are batteries and telegraphing apparatus.

The general state of repair of the line, description of tunnels, cuttings, and embankments; the maximum gradient on the line.

The number and direction of the junction lines, and whether they lead from districts whence supplies may be drawn.

The suitability of the railway to be used as a road for marching infantry.

Any other miscellaneous information that may strike the officer as being likely to prove useful in time of war should be inserted in the report.

In drawing the plan of a railway station or junction to show its sidings, points, &c., in detail, it is usual to exaggerate the widths, or make the transverse scale three or four times larger than the longitudinal; *each pair* of rails being shown by a single thick line.

Reconnaissance of a Position.

A good sketch is far preferable to any written description of a position, for the information of one who understands the subject. But, on service, there will seldom be time to make more than a very rough sketch, supplementary of the written report, which will in such a case be much more ample than that given below, and will explain all points in which the sketch is deficient. However pressed for time the reconnoitring officer may be, he should try to convey as much information by his sketch as circumstances will permit.

Very frequently the officer on active service will be provided with the Government map of the country (if the scene of operations be in a civilised country), and his duty will be to draw up a report furnishing all the tactical information in which the map is deficient, in view of the military operation in progress. This method of recording information, though not *the best*, might be the only method *possible*.

Sketches of positions are made on a larger scale than those of roads, as they must show accurately certain details which would be unnecessary in the latter. The road and the positions will usually be simultaneously sketched by different officers. The cavalry sketching case will be large enough to contain the sketch of small positions at the scale of 4 or 6 inches to a mile if the work be judiciously placed on the paper; and accuracy sufficient for the purpose may be obtained. There would rarely be time to execute the sketch with prismatic compass or plane table, so as to give the required information early enough to allow of its being acted upon; the latter instruments would be more suitable for the purpose of depicting the scene of action, after the event, to accompany despatches.

It is necessary to consider briefly some of the conditions which a

good position should fulfil, and the points which constitute strength and weakness, in detailing the headings under which the report on a defensive position will be framed.

A reconnoitring officer will be called upon either to examine and report on the general capabilities of certain positions; or else to find positions suitable for defence by a force of a certain strength. In the latter case, much judgment is required; a position suitable for defence by 20,000 men might be quite indefensible by 10,000. On the other hand, to overcrowd a position in these days of far-reaching fire is to incur avoidable loss of life, so that the same position might be too cramped for defence by 40,000 men.

The composition of the force must also be taken into consideration, and ground selected that will favour the action of the arm in which it is strongest.

The number of men per mile suitable for the defence of a position varies greatly according to the ground and the amount of cover it affords. 5000 infantry per mile, or 3 per yard, including reserves, is the usual estimate for an average position,* *vide* Field Exercise, or including all arms and reserves 5 men per yard.

A position should have 500 or 600 yards of depth, sufficient for manœuvring and for moving troops from one part to another without undue exposure. It will be advantageous that the ground should dip slightly in rear of the position so as to conceal these movements. Reserves will gain little real protection from distant fire, though thus hidden from view. They will, however, derive more shelter from fire as the assailant gets to closer quarters.

In most positions there are some portions naturally strong or difficult to attack; these require few defenders, the number spared from them can be added to the defence of weak parts of the line. Weakness and strength may be said to consist chiefly in the suitability, or the contrary, of the ground for the development of the defenders' rifle fire. Hence if the ground over which the assailant must advance is rugged and broken, or closely fenced, it will afford him cover from fire, and enable him to mass large numbers for a final rush on the position. Such a position, though apparently difficult of access, is decidedly weak.† On the other hand, a strong position would be one in which good cover is afforded to the defender's shooting line, behind banks, &c., and having in front clear, open, and gently sloping, or nearly level ground, over which the assailant must advance for some hundreds of yards exposed to rifle fire. As a rule gentle slopes are easier seen into and defended, than steep ones.

A good position should command a view of the movements of an assailant, and should not be itself commanded by any higher ground within artillery range. Large woods are dangerous features in front or on the flanks of a position.

It will be well if the flanks can be placed so as to be supported by natural obstacles, such as marshes, rivers, or lakes. Should there be no such natural advantages every effort should be made to strengthen them artificially.

There should be artillery positions, whence the ground over which the enemy must advance may be well seen, particularly the ground beyond rifle range and the roads leading to the position, so that

* Both the French and English at Waterloo had at the rate of 12 men for every yard of front.

† Majuba is a case in point.

artillery fire may oblige him to deploy at a distance. Infantry officers, as a rule, underestimate the effective range of artillery. Artillery is the only arm that can be advantageously posted behind a lake, swamp, or other impassable obstacle, its action being only defensive.

A good position should not be divided perpendicularly by a stream, ravine, or other feature difficult to pass, which would impede the defenders' lateral communication, and enable the attackers to concentrate their real attack on one side of the position. Such an obstacle outside the position and on the enemy's side would impose similar disadvantages on him, and favour the defence.

A wood may be a source of strength or the reverse, the latter if it is too extensive to be fully occupied. Wood fighting is distinguished by the tenacity with which the defenders cling to cover; and if the enemy gain a footing in it, it becomes a source of great danger, as it may enable him to mass troops for an assault.

The points that call for special examination in the ordinary reconnaissance of a wood as connected with that of a road have been already enumerated. In connection with a position, the report will enter more closely into details as to its extent and form; the communications and paths through it; the average circumference of the trees; the nature of the underwood and its penetrability; the means to be adopted for the defence of the edges nearest the enemy; whether the timber is suitable for abattis to be placed at the salient and most exposed portions: whether parts of the edge flank other parts; whether the wood is quite isolated, or is connected with neighbouring woods by scattered timber; whether there is any fold of the ground, or any bank that would give cover to an enemy close in front of it. Banks or other cover in rear of the wood whence fire might be brought to bear on its near edge to prevent the enemy from issuing from it, in case he should succeed in occupying it.

Though there is now greater necessity than ever for enterprise and intelligence in cavalry during the events preliminary to an engagement, the *rôle* of this arm on the battle field is much reduced in late years by the increased power of infantry. The reconnoitring officer will be observant of open ground, especially towards the flanks, suitable for the movements of cavalry, also of hollows in the ground, or concealment afforded by woods where they can be placed out of sight and in readiness to seize any opportunity of dashing on the assailants if they should get a footing in that part whilst in a confused and disordered condition; ready also to check turning movements and gain time for the defenders to make dispositions to meet them.

Farms and villages in front or on the flanks may be easily converted into strong posts. In reconnoitring them with that view, the following points will be noticed in addition to those previously enumerated.

Whether they are compact or straggling; the exterior of the village surrounded by walled gardens suitable for defence; whether the fences beyond the village would cover the enemy in his advance, and if so whether they can be easily levelled. Means for retarding his advance; whether the village is commanded by artillery positions on the enemy's or defenders' side. All details concerning a building, such as a church in the village, suitable for a réduit.

The roads leading through the position and those along it must be closely examined. If the intention is to act chiefly on the defensive, some of the roads towards the enemy and on the flanks might be obstructed by felled trees; but unless the defenders are greatly out-

numbered or demoralised, or unless the object is merely to gain time, the attitude of passive defence is one that can lead to no good results. Hence with a view to the possibility of assuming the offensive, the road should not be destroyed; bridges may, however, be mined in readiness for demolition at the last moment; this applies particularly to those in rear of the position, by the destruction of which, after the rearguard has retired, the pursuit may be checked.

The best line of retreat is from the centre of the position, leading straight to the rear; the worst is parallel to the front, as any success of the enemy on one flank would imperil the communications. Fences in rear of the position are favourable in case of a retreat, enabling the defenders to rally and dispute the ground.

If a position is to be occupied for any length of time, wood and water should be within easy reach.

A position containing many of the above advantages will seldom be found, nor will a commander as a rule have the opportunity of choosing his position and there awaiting attack. He has usually to make the best of the ground on which the turn of events has placed him, fortunate if within a few miles he can find such as will give his troops any advantage.

The reconnoitring officer may be called upon to report on the best line for the outposts in connection with a defensive position. It would be needless here to repeat the well known principles that will guide his selection. The general line of the outposts can be sufficiently indicated on the existing maps by colour. The exact distribution will be arranged by the commander of the outposts.

1. GRADATIONS ADMITTING OF MANŒUVRES.

5°	10°	15°
INFANTRY. Can move in formation.	INFANTRY. Close movements difficult.	INFANTRY. Can only move a very short distance in order.
CAVALRY. Can move with order—its charge more effective up hill than down.	CAVALRY. The charge possible only up hill and for a short distance.	CAVALRY. Can only trot up hill a short distance, and walk down hill.
ARTILLERY. Fire more effective down than up hill.	ARTILLERY. Moves with difficulty — its effectual and constant fire ceases.	ARTILLERY. Moves with great difficulty — its fire ceases entirely.

2. GRADATIONS WHICH MAY BE ASCENDED AND DESCENDED SINGLY.

20°	25°	30°
INFANTRY. Cannot move in order, can only fire singly with effect. CAVALRY. Can still ascend at a walk, and descend the slope obliquely.	INFANTRY. Can only move in extended order. CAVALRY. Light Cavalry can only ascend and descend obliquely, one by one.	INFANTRY. Can only move in extended order and very slowly. CAVALRY. As before, but with great difficulty, and when the slope is of soft earth.

3. GRADATIONS WHICH MAY BE CLIMBED UP.

35°	40°	45°
INFANTRY lightly equipped may ascend slowly in extended order.	As before with the help of their hands.	Men accustomed to hilly country may ascend, holding on by their hands, but with danger of falling.

The nature of the surface, as well as the steepness, affects the capabilities of ground for the movement of troops, and affects the three arms differently. Thus, for infantry the ascent of a steep slope, such as 25°, is easier if the surface is rocky and rugged than if it is smooth turf affording bad foothold; for cavalry the latter is the easier.

It is not the business of the reconnoitring officer on service to suggest the proper method of occupying a position, unless specially ordered to do so;* he will usually merely give the superior officer the result of his observations, explain the points of weakness and of strength, its general capabilities, and suitability for the action of the three arms, the means which exist for obstructing an assailants' advance and retarding his pursuit, the nature of the communications, &c., and leave him to draw his own deductions.

These reconnaissances will usually be executed under the orders of the general by staff officers. An engineer and an artillery officer will be employed in examining the specialities connected with their branches. The former in arranging for demolitions, obstructions, and defensive works, the latter selecting sites for emplacements and gun pits, and making every preparation for their execution if approved by the general.

For purposes of instruction, and as a tactical study, an officer may be called upon to explain by sketch and memoir what he considers to be the proper distribution of the different arms; the works he would undertake to strengthen the position; obstructions to detain the enemy

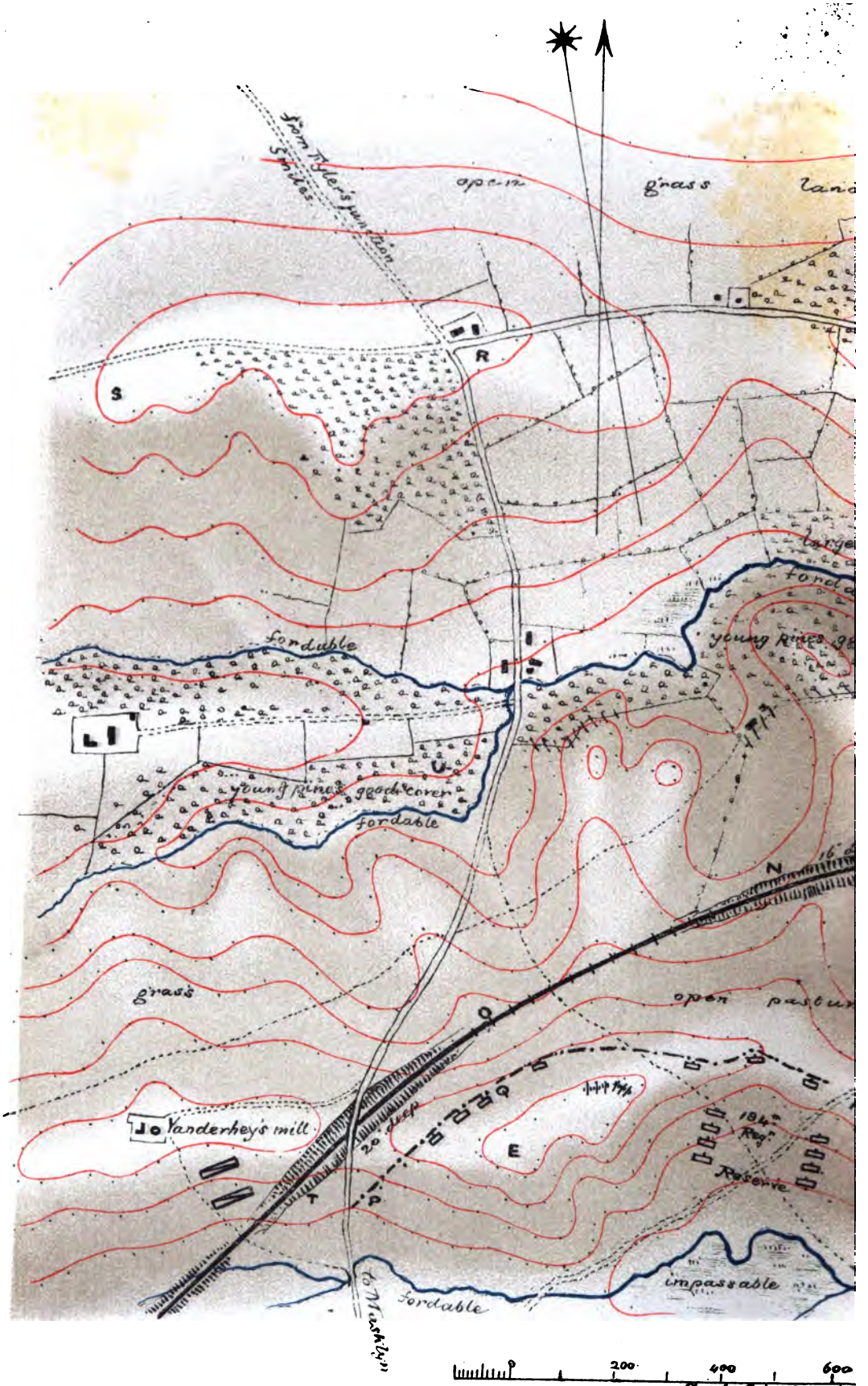
* Napoleon I, in his instructions on reconnaissance, ordered that the word "l'ennemi" was not even to be made use of.

under fire; demolitions to deprive him of cover, &c. In fact such a reconnaissance will test his knowledge both of military sketching, of tactics, and of field fortification.

In considering the capabilities of a position it should be regarded from the side of the enemy's advance, as much as from the defenders' point of view.

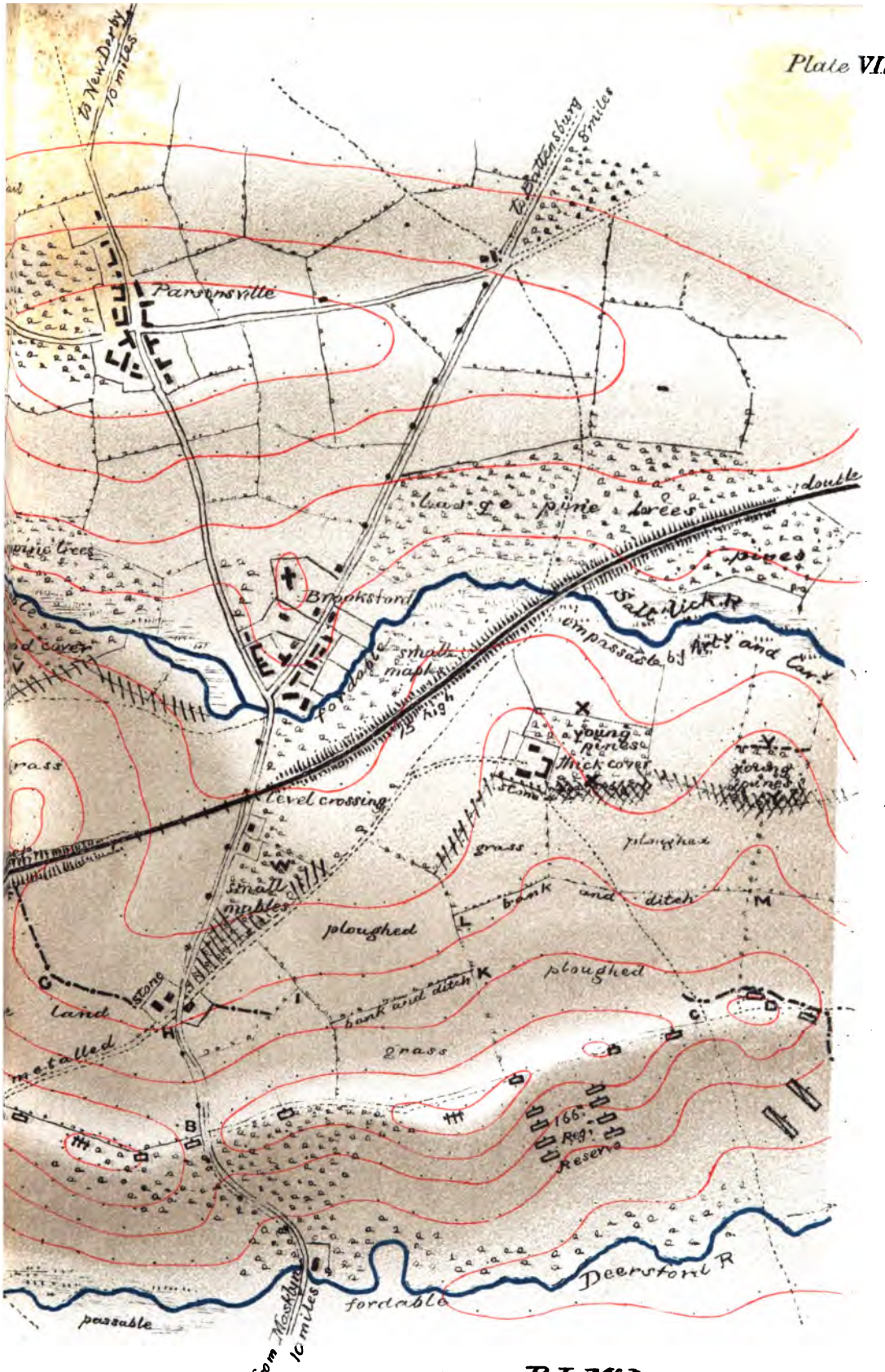
The following are the headings under which most of the subjects connected with the defensive positions can be reported on:—

1. THE POSITION.—Description of all that is not already explained by the sketch concerning its form; the direction in which it faces; its flanks; any remarkable or dominating point in it; the condition of the ground; whether soft and heavy for movement, or the reverse; wood and water in case it is intended to encamp or bivouac on the ground; probable direction of the enemy's attack; reasons for this conclusion.
2. ADVANTAGES.—Good positions for artillery, with wide and distant range commanding the approaches and flanks; good points d'appui on the front or flanks; good cover for infantry, with ground in front suitable to the development of rifle fire; cover for second line and reserves; communications in a lateral direction; communications to the front and direction in which a counter stroke could be delivered or the offensive assumed; communications with the rear; flanks well posted; extent suitable to the force; natural obstacles to the enemy's advance.
3. DISADVANTAGES.—No position will be found without some of the following disadvantages:—Limited range for artillery, or the ground affording better positions for the enemy's artillery; extent unsuitable to strength, or its nature to the composition of defending force; no favourable ground on which to rest the flanks; cover for the enemy during his advance; bad cover for the firing line, or in such a position that fire would not be effective; absence of cover in convenient places for the second line and reserves. Inconvenient communications.
4. THE COUNTRY IN THE VICINITY.—General description of the surrounding country beyond the limits of the sketch; positions or strong points on the line of retreat, such as farms or villages at which pursuit might be checked; the distant view to be obtained.
5. COMMUNICATIONS.—Description of roads, paths, &c., perpendicular to the position and lateral; also those from the front towards the flanks.
6. BRIDGES.—As in road reports.
7. RIVERS.—As in road reports, but with more particular information as to the points of passage and nature of the banks.
8. WOODS.—As previously explained.
9. FENCES.—The general description of fences on the ground, and particular description of those which it is proposed to utilise for the defence.
10. OBSTRUCTIONS AND DEMOLITIONS, TRENCHES, AND OTHER WORKS.—Details of these to be given on a separate form, showing time required, number of reliefs, number of men in each relief, and tools required.



Shelter trenches shown thus ——.——.——.
First line TQNFCHIKLM
Second line PQABCD
Advanced posts WXV

Plate VII.



R.L.M.cD.

Major ..... Reg.t

24th June 18—

The reconnaissance of a small position is here given, not in illustration of tactical theories, but of the topographical part of the subject. Plate VII.

Instructions. General Idea.

A division, composed as shown beneath, is moving northwards from Maskelyn, to meet and check a stronger force which is advancing by the New Derby and Battensburg roads, and is reported to be within four days' march.

An officer is instructed to precede the division with an escort, in order to report on the country about Parsonsville, and the capabilities of any position he can find suitable for opposing the enemy's advance. Works proposed, to be such as can be executed within six hours after the arrival of the division.

2 brigades of infantry (6 battalions each, 800 strong).
1 divisional regiment.
1 regiment of cavalry, 600 sabres.
2 batteries of field artillery.
1 company Royal Engineers.
Reserve ammunition column.

REPORT ON POSITION SOUTH OF BROOKSFORD.

The Position.—Faces north, along the ridge between the Deersfort and Saltlick rivers and *à cheval* the Maskyln-Parsonville road. Its character as shown in the accompanying sketch. Surface of the ground on the west side of the position is firm and even, covered with long grass, and suitable for rapid movement of all arms.

The east side of the position is somewhat obstructed by light fences, rendering it unsuitable for cavalry action. Cultivation of fields shown in sketch.*

Advantages.—Commands the ground in front as far as the Parsonsville ridge, and enfilades the enemy's line of advance to a distance of about $1\frac{1}{2}$ miles.

The ground for the most part suitable for the rapid movement of all arms; where there are fences, communications can be easily prepared through them.

The fences opposite the east half of the position are of a nature to be quickly converted into breastworks and shelter trenches, and are favourably situated for commanding the issues from woods and farmsteads in their front, which cannot be occupied.

From A to C there is good cover, well placed for a second line of defence.

On the west half of the position the railway from O to F is favourable to the defence, affording cover in a good position for the firing line.

There are commanding positions for artillery all along the

* It would have been useless reiteration to explain such matters as that the general height of the ridge above the stream is about 100 feet, slopes in front under 6°, &c., all this being graphically expressed by the sketch. Were the Officer uncertain of his ability to express any such matter accurately by the sketch, he should explain it in the report.

ridge, and guns can be moved from one part to another, out of sight. Reserves are covered from view by the form of the ground, and from fire at close range, with facilities for movement to any part of the line.

Artillery has a wide field of fire towards both flanks.

Cavalry can be posted on the flanks out of sight, yet well forward and in positions favourable for counteracting any turning movements.

Disadvantages.—As regards artillery, the range towards the front is limited; the most distant ground commanded by the position is within 1,400 yards, so that from the commencement of an action artillery will be exposed to rifle fire. There is no more retired artillery position available, whilst the enemy will have the advantage of high ground 2000 yards north of Parsonsville (beyond the sketch), whence, with a range of 3400 yards, it may be anticipated that some of their guns will, at the commencement of an action, shell the position; this fire would search the reverse slope of the hill, and be very effective against the reserves.

The position, though strong in front, is too extensive for the force, and there are no points d'appui for the flanks. In this respect the left flank is worst placed, on account of the railway cutting, which it will be difficult either to hold or to deny to the enemy in case he should direct his attack on this flank. He can enfilade the cutting from a distance of 2200 yards; no fire can be directed into it by the defenders from the main position. An extension of the line to Vanderhey's, with the view of including it, would attenuate the line of defence unduly.

Recommendations for the defence of this cutting are given in the detail of work.

Along the front of the position are patches of wood, the eventual occupation of which by the enemy cannot be prevented, though issue from them can be rendered difficult by the obstructions proposed and by effective rifle fire.

The village of Brooksford and the railway embankment south of it are too far in advance for occupation, and are ill situated for defence; the embankment is, however, enfiladed from the artillery position at E, and from the proposed shelter trench FG.

The lower part of the slope in front and for 600 yards west of V, near the stream opposite the centre, is convex in section, and is therefore dead ground, greatly in favour of the attack.

Most of the ground over which an assailant would advance is cultivated, and soft enough to be unfavourable to ricochet.

The Country in the vicinity.—The range of heights in the sketch extends for 2 or 3 miles beyond each flank, its general character being similar to that sketched.

The Parsonsville ridge is commanded by high ground north of it, within 2000 yards, rendering it untenable as a position.

South of the Deersford river the country is gently undulating for some miles, and intersected by fordable streams every 2 or 3 miles. It is mostly unfenced, firm, open, and suitable for movement of the three arms; it is interspersed with a few patches of forest.

There is a position somewhat similar to that sketched, but less strongly marked, within 5 miles, south of the Deersford.

The view of the country and of the roads by which the enemy is advancing is much restricted by fences and trees.

Communications.—Perpendicular to the position the roads are metalled to a width of 18 feet, split rail fences.

The paths are good firm tracks, unfenced. All the roads north of the Saltlick river are metalled and in good order.

Lateral.—The road BC is unmetalled, but firm and suitable for artillery, fenced on the north side as detailed below, unfenced on the south side.

There are no roads leading round or near the flanks from the front, but the country is generally suitable for movement in these directions.

Bridges.—The bridge over the cutting near E is of brick, 70 yards long, 30 feet high, 15 feet wide; 3 semicircular arches, centre, 25 feet span; side arches, 12 feet span; piers, 3 feet thick.

The remaining bridges are of little tactical importance, movement not being restricted to the roads at this season.

Rivers.—Deersford, average depth 2½ feet; width, 18 yards; rapidity, 2 miles an hour; gravel bottom; banks firm, except as shown in sketch. Not liable to floods at this season; passability marked in sketch.

Saltlick, average depth, 2 feet; width, 20 yards; rapidity, 2½ miles an hour; gravel bottom; banks firm, except in the places shown in sketch. Not liable to floods.

Woods.—U. Penetrable by skirmishers; 20 year old plantation, trees average height 18 feet; stems, 6 inches thick.

V. Similar to U.

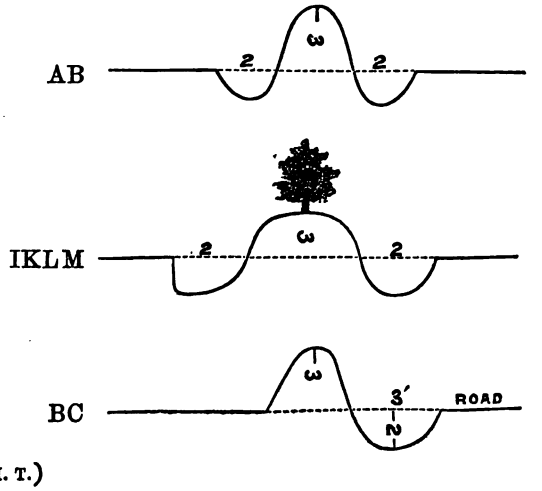
W. Thick plantation; trees, average height, 10 feet; thickness, 3 inches.

X. Trees rather larger than U; thorn underwood, difficult to penetrate.

Y. Similar to U.

Fences.—Round V, X, and I are banks.

AB, BC, and IKLM, banks and hedges, as shown below.



The officer may further be expected to show in detail the distribution of the defending force to various parts of the position in the following form:—

DISTRIBUTION OF TROOPS.

Name of work.	Regt.	Officers.	N.C.Os.	R. & F.	Remarks.
From L to M, &c.	167th	12	20	400	In extended order, &c.

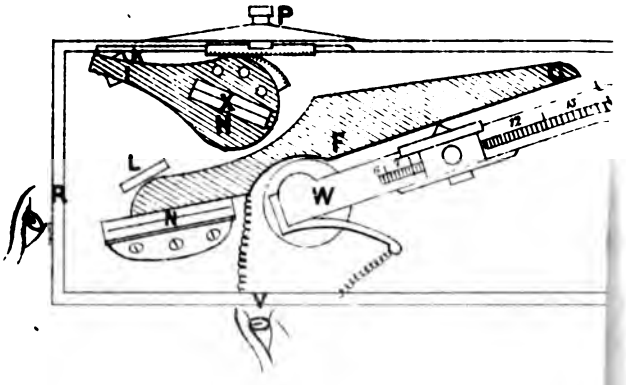
The details of work to be executed may be shown in the following form, if required:—

DETAIL OF WORK.

Name of place and description of work.	Strength of working party.				Number of reliefs.	Number of hours.	Tools, &c., required.									Remarks.
	Corps.	Officers.	N.C.Os.	R. and F.			Picks.	Shovels.	Billhooks.	Crowbars.	Spades.	Saws.	Axes.	Powder.		

The considerations connected with these forms belong to the subjects of tactics and field fortifications, and are therefore not entered into here.

Plan of the rangefinder with the cove -



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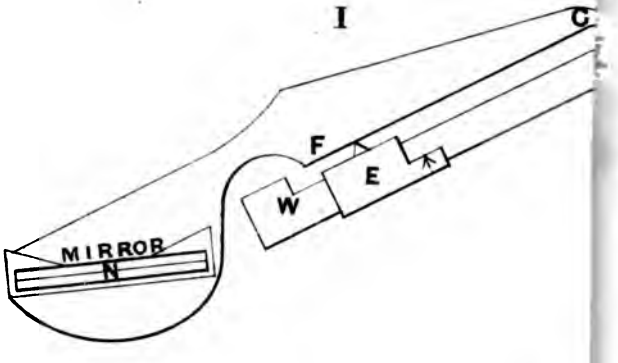

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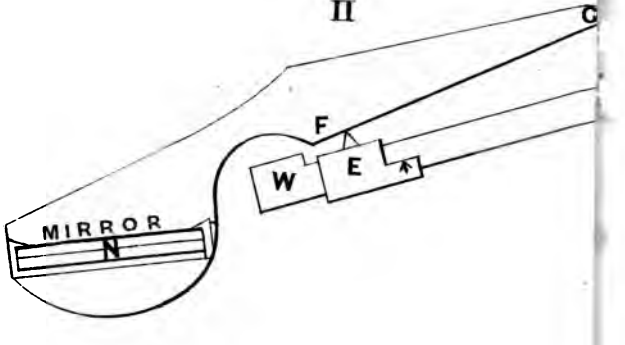
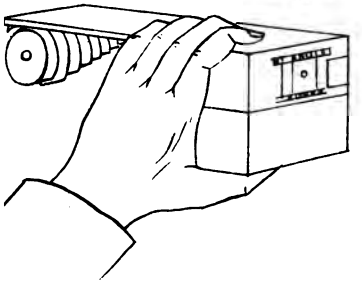
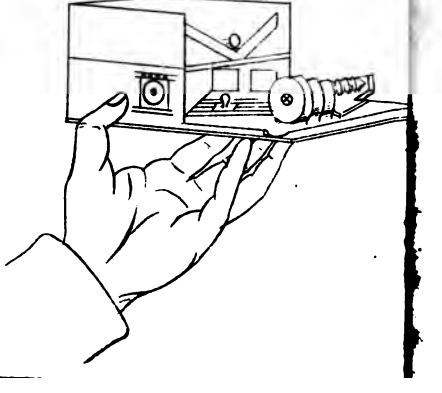


Taking the right angle



Taking the Base

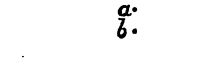


SECTION XII.

THE RANGEFINDER.

The problem of rangefinding may be briefly described thus:—It is evident that if a line be drawn from *a* towards a distant point *x*, another line from *b* (a point a little on one side of *a*) cannot be

FIG. 55.



parallel to *ax*. The measure of this non-parallelism, or parallax, determines the distance of *x*. The greater the distance between *a* and *b*, the more accurate would be the solution, but it being an essential condition in rangefinding that this distance or base shall be small, it becomes necessary to employ instruments of accuracy, elaborate and delicate in proportion to the shortness of the base used.*

The present Service rangefinder (Watkin) determines distances about 20 times the length of base, and is very portable. As the base may be any convenient length within certain limits, and is not measured but found by observation, the instrument can be used in any sort of ground.

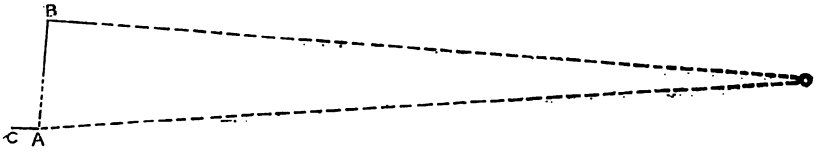
The principle is this, AO (Fig. 56) being the distance to be found:—

Three pickets, A, B, C, are used:—

I. B is placed so that ABO shall be a right angle.

II. C is placed perpendicular to AB at a constant measured distance (in order to find the length of AB by observation). The smaller the angle that AC subtends at B, the greater the length. The instrument solves this automatically.

FIG. 56.



* The Berdan rangefinder adopted by the Russians, works with a base of only 2 metres (about 6½ feet). It consists of two powerful telescopes, one of which is capable of slight horizontal movement. The apparatus is carried in a wagon; it costs about £500. Other rangefinders containing their own base have been invented, but not adopted for military purposes, such as Piazzi Smyth's, in which the base was about 2 feet. Such instruments require high telescopic power, and are delicate. Both the German "kippregel" and the French "alidade autoréductrice" are much used in surveying abroad. They measure distance by observation of a staff about 13 feet high, held at the distant point; but under such conditions they can hardly be classed as rangefinders.

(M. T.)

III. Now ABO being a right angle, it only remains to observe at A, the quantity by which BAO is short of a right angle, and the length AB being known, the instrument determines BO (practically the same as AO) mechanically.

Description of the Rangefinder.

The equipment consists of—

The rangefinder.
A metallic cord, 6 yards long.
Three pickets fitted with discs to render them visible.

On a steel arm FG, pivoting at N (Plate VIII), is fixed a mirror N, similar to the index glass of an ordinary sextant. Another glass, X, corresponding with the horizon glass of a sextant, is fastened to a shorter arm HI, capable of revolving round a pivot at H, and fitted at I with a screw for adjustments. This arm traverses 45° between two blocks K and L, and is moved by the rack Q, actuated by the knob P. When the screw I is pressed against the block K, as shown in the figure, an optically true right angle is given to the eye at R.

Against the edge FG bears a steel projection on the sliding collar E. This collar with ↑ engraved upon it, slides on a metal arm WD, pivoted at W, and graduated with a scale of yards marked from 60 to 120, representing the number of yards within which the base for the operation may be taken.

At the extremity of WD is a block D, against which the point of the screw Y bears. This screw belongs to the cylinder T, on which is marked a scale of ranges from 400 to 5000 yards. The range is read opposite to the ↑ engraved on a collar which surrounds the cylinder. When the range cylinder is turned, the arm WD is moved, communicates motion to the arm FG, by the projection at E, and thereby alters the angle of inclination of the mirror N.

The amount of motion which a movement of the cylinder communicates to N depends on the position of the sliding collar E, which is set to the proper graduation for the base used, as presently explained.

The base is usually between 60 and 120 yards. The longer the base the more accurate the result, because the greater the parallax. In order that the scale of yards engraved on the cylinder shall give the range in every case, independent of the varying parallax due to varying length of base, the following arrangement is made for placing the mirror N at a compensating angle of inclination.

The mechanism may be recognised in the figures. The cylinder being set with the ↑ reading 0, as shown (Plate VIII, 1), the edge of the arm WD is parallel to FG, so that no motion of the sliding collar E along the base scale will alter the position of the mirror N. But when the cylinder is unscrewed (Plate VIII, 2), the arms WD and FG cease to be parallel, and it is seen that the nearer E is placed to D, the greater will be the alteration in the angle of the mirror produced by any revolution of the range cylinder. It is evident from the above that the graduations on the cylinder and base bar WD are proportional to one another, and therefore the readings may be doubled, halved, &c., at pleasure. Also that the graduations may be taken in feet, yards, or any other measure.

The two eye-holes R and V are bored obliquely, showing the direc-

tion in which they are to be looked through. The scale of ranges on the cylinder is arranged thus :—

From 400 to 1500, the hundreds are subdivided into divisions of 10 yards.

From 1500 to 3000 there is only room to divide each hundred into four, of 25 yards each.

From 3000 upwards the divisions represent 50 yards.

In continuation of 990 the divisions are marked 10, instead of 1000, and so on. Thus 24 indicates 2400 yards.

The numbers are read from right to left.

The Operation of Rangefinding.

(1.) Supposing the distance of O from A (Fig. 56) to be required.

Plant the picket with square leather head and strut, at A, the flat side of head turned to the left, and the strut or support to the rear. Now pace about 100 yards at about right angles to AO. Open the instrument, push the arm HI against the stop K by moving the button P away from K (Plate VIII.) Set the cylinder to zero, hold the instrument as shown "taking the right angle," and look through eye-hole R at object O, through the unsilvered part of the horizon glass X.

The picket A will appear reflected in the silvered part of the glass. Should it appear to the right of the object, the observer must retire, if to the left advance until A exactly coincides with some well-defined portion of the object. This instrument is now at the right angle OBA. The observer plants the picket B between his toes, and verifies its position by resting his hand on the top of the picket (in such a position that the index glass N is immediately over the picket). On looking through the instrument again any slight error can be rectified by forcing the head of the picket to or from him.

The placing of picket C is performed thus. An assistant, as soon as he sees the picket B planted, lays one of the cross lines engraved on the head of the picket A on B, hooks the 6-yard cord to A, and plants C, so that the centre of the disc is at the full distance, and in the direction given by the other cross line on the head of A.

If there is only one observer he places C before going to B, to find the base. He places it slightly to the left of the continuation of the line AO (Fig. 56), so that the angle BAC may be nearly a right angle. The shorter the range the more must C be to the left. For a range of 1000 yards it should be placed one pace to the left.

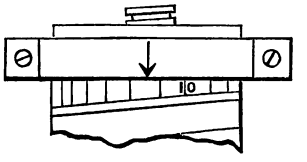
(2.) For measuring the base AB, the length of AC (Fig. 56) being known.

The angle which AC subtends at B is measured by reflecting C on to A. If then the sliding collar be placed at the distance representing AC on the base scale, the cylinder will mark the distance AB. As AC is always 6 yards, the sliding collar is for this operation placed at the mark 6 (representing 60 yards in the range triangle). The result obtained for the distance AC is therefore ten times the true one, thus the same scale on the cylinder does for both bases and ranges, if only in the former we divide by 10. It is advisable, however, always to read this scale as for ranges, multiplying the base scale by 10, so as to avoid confusion. Thus, a base of 100 yards would be read as 1000 yards, and the sliding collar set to 10. If a tape of 10 yards be used, the same result for AB would be obtained by setting

the sliding collar to the mark 10 before reflecting the image of C on to A.

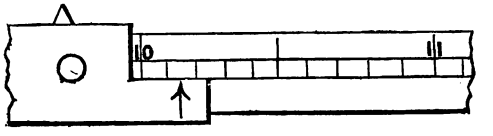
If the ↑ points thus, Fig. 57, it would read 1015 (representing 101·5 yards base).

FIG. 57.



and the sliding scale would be set thus:

FIG. 58.



Hold the instrument as shown ("taking the base"). Face A standing with B between the toes and look through eye-hole V, being careful not to disturb the position of the picket; A and C will be seen though the plain part of the glass X, and their reflections immediately below them. Turn the cylinder to the left with the right hand until the reflection of the vertical line on the round disc C, coincides with the vertical line on the square disc A. The length of the base AB may now be read on the cylinder, and the sliding collar E set to the same figure, as already described.

The summary of the operation of finding the base is—

1. Set the sliding collar E to 6 on the scale WD.
2. Push the arm HI against the stop L by means of P.
3. Bring C and A together optically by revolving the cylinder.
4. Read the cylinder and set E to the corresponding figure.

(3.) The third observation is made at A. The observer stands with the picket between his toes; pushes the arm H against the stop K; holds the instrument as in Plate VIII; faces towards O, and looks through the unsilvered part of the glass X. He now turns the cylinder until the picket B, reflected in the lower part of the glass, coincides exactly with O; he may verify the observation as before, by placing the instrument over the picket itself. The range is now read opposite the ↑.

If it should be inconvenient to set off the base to the left, it may be taken on the other side by reversing the operation, as detailed.

The most general source of error in the observations is the failure to observe precisely the same point of the object from both ends of the base. To guard against this with objects not clearly defined, it will be necessary for the observer to keep his attention on the point whilst he shifts from one end of the base to the other.

Case II. When the base is limited to under 60 yards, or the range is under 600 yards.

The operation is, as above described, with these exceptions. After

placing the picket B at the right angle, set the sliding collar to 12 before making the pickets A and C coincide by revolving the cylinder.

The true range is half that read on the cylinder.

Case III. When the base is limited to over 120 yards, or the range is beyond 4000 yards.

The subsidiary base AC is made 12 yards, instead of 6 yards; or the base being kept 6 yards, the sliding collar is placed at half that denoted as the length of the base by the cylinder.

The true range by either method is double that shown by the cylinder. It is advisable to use Case III, when time will permit, for ranges over 2500 yards.

Adjusting the Instrument.

The instrument should be tested before being used, and adjusted if necessary. These adjustments should never be practised for instructional purposes on any but an old unserviceable instrument.

Set the cylinder as far as it will go to zero. Press the sliding collar E back to 6 on the scale. Press the screw I against L by the nut P.

If the instrument is in proper adjustment, by looking through the eye-hole V at any sharply defined vertical line, such as a pole or side of a house, about 200 yards away, two images of it will be seen exactly over one another, one by direct vision, the other by reflection.

If they do not exactly coincide, unscrew the key which is inside the cover of the instrument, apply it to the square of the screw I, and turn it until the two images are in line. Move the arm HI backwards and forwards several times, replace it against the block, and see that the adjustment has been properly effected.

The length of the wire cord should occasionally be tested by a true standard measure.

Under certain circumstances the rangefinder may be useful for surveying. For instance, as in Zululand, where surveying operations were generally limited to the line of route, the distance of adjoining peaks, &c., could be found by the rangefinder, and their direction by the compass; and thus a number of conspicuous points could be placed in their correct relative positions on paper. The surveyor seizing every opportunity of observing the lie of the country between these points, filled in the sketch by eye.

A good operator, with a plane table and ruler with vanes, could obtain ranges under similar conditions to those described, that is, distance about twenty times the length of the base. But on service the rangefinder is more likely to be available, and men trained in its use could assist the officer in surveying.

The rangefinder can be used for measuring small angles between objects. Push I to L by the knob P. Adjust E to 10. Look through eye-hole V, and make the two objects coincide by revolving the cylinder (as in taking the base).

Note the range on the cylinder, and take the corresponding angle from the table. Thus, supposing the reading on the same cylinder to be 1200 yards, the range would be 4° 45′.

ANGLES CORRESPONDING TO RANGES.

Range.	Angle.		Range.	Angle.		Range.	Angle.	
yards.	deg.	min.	yards.	deg.	min.	yards.	deg.	min.
5,000	1	9	2,100	2	44	1,200	4	45
4,500	1	16	2,000	2	52	1,150	4	58
4,000	1	26	1,950	2	56	1,100	5	11
3,500	1	39	1,900	3	1	1,050	5	27
3,400	1	41	1,850	3	6	1,000	5	43
3,300	1	44	1,800	3	11	950	6	1
3,200	1	47	1,750	3	16	900	6	20
3,100	1	51	1,700	3	22	850	6	42
3,000	1	55	1,650	3	29	800	7	7
2,900	1	59	1,600	3	35	750	7	35
2,800	2	3	1,550	3	42	700	8	8
2,700	2	7	1,500	3	49	650	8	45
2,600	2	12	1,450	3	57	600	9	28
2,500	2	18	1,400	4	5	550	10	18
2,400	2	23	1,350	4	15	500	11	19
2,300	2	29	1,300	4	24	450	12	32
2,200	2	36	1,250	4	35	440	14	2

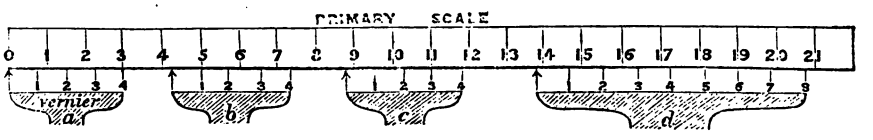
SECTION XIII.

THE VERNIER.

The graduation of the more accurate class of instruments is read by means of the "vernier," a movable scale, the divisions of which differ very slightly from those of the graduated arc, or primary scale to which it is applied.

Its principle is this. If any number of divisions of the primary scale, say three, be taken for the length of the vernier, and divided into four (or one part more), each of these vernier divisions will be smaller than each of the primary divisions by $\frac{1}{4}$th, so that if the index (↑) of the vernier coincide with O of the primary scale (*a*, Fig, 59), the vernier division 1 will be distant $\frac{1}{4}$th primary from 1 of the upper scale; vernier 2 will be $\frac{1}{2}$ short of the upper 2; vernier 3, $\frac{3}{4}$ short of upper 3.

FIG. 59.



Then if the vernier be placed with its division 1, coinciding with one of the primary scale divisions as at *b* (Fig. 59), the index has passed the preceding number 4 by $\frac{1}{4}$th, and the vernier reads $4\frac{1}{4}$. In position *c* it reads $8\frac{3}{4}$.

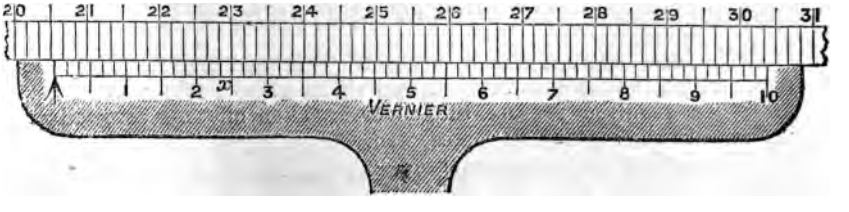
If it were required to construct a vernier to read eighths of the same primary scale, it would be so divided that there might be a difference of $\frac{1}{8}$th between each of the divisions of the two scales.

This would be obtained by taking for the length of the vernier seven primary divisions, and dividing it into eight parts; *d*, Fig. 59, reads $13\frac{6}{8}$.

Hence it is seen that the greater the number of primary divisions, of which the vernier consists, the more minutely does it read.

Let it be required to construct a vernier to read 10 seconds on an arc graduated to 10 minutes. 10 seconds = $\frac{1}{6}$th minute or $\frac{1}{60}$th of a primary division, therefore the vernier would consist of 59 of these divided into 60 parts. This is the ordinary arrangement in the nautical sextant.

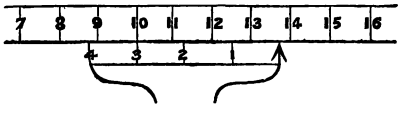
FIG. 60.



In the figure the index has passed 20° 30′, and the vernier shows 2′ 30″ at x, so that the reading is 20° 32′ 30″.

The same difference of $\frac{1}{4}$ between primary and vernier divisions, as is shown in Fig. 59 a, might be obtained by taking for the length of the vernier five of the former and dividing it into 4, then each vernier division would be $\frac{1}{4}$th *larger* (instead of smaller, as in the previous case) than the primary divisions. In consequence of this the divisions of the vernier must be numbered, and the coincidences counted in the retrograde or contrary direction to those of the primary scale; the reading in Fig. 61 is $13\frac{3}{4}$. This arrangement is only employed in certain theodolites and mercurial barometers.

FIG. 61.



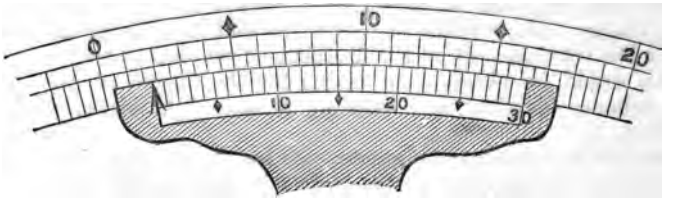
From the preceding it will be seen that the rule for calculating the construction of a vernier is,—

Let a = length of a division on the primary scale.
b = „ „ vernier scale.
n, the number of divisions of the vernier.
d, the difference between a vernier and a primary division.

$$d = a - b, \text{ and } nb = (n-1)a,$$
$$\text{therefore } d = a - \frac{(n-1)\,a}{n} = \frac{a}{n}$$

In both the pocket sextant and the 5-inch theodolite, presently described, the divisions of the arc are half degrees, or 30 minutes, and the vernier is constructed to read minutes, and therefore consists of a length of 29 primary divisions, subdivided into 30 parts, Fig. 62.

FIG. 62.



To read the angle, first note the number of the arc which the index of the vernier has passed. Next examine the vernier to see which of its divisions coincides with one of the arc divisions, add this quantity to that first noted. In the figure, the index has passed 1° 30′, and the vernier reading is 15′, making the total reading 1° 45′.

THE POCKET SEXTANT.

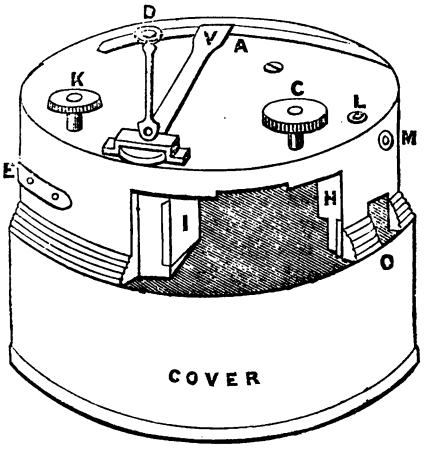
This instrument is shown, Fig. 63. It is used for measuring the angle which the distance between two visible objects subtends.

When required for use the cover is taken off and screwed on underneath the sextant, as represented.

The parts of the instrument are:—

I. The index mirror. H, the horizon glass, the upper half of which, only, is silvered. V, the index arm which moves with the index mirror, and shows its position by a vernier on the graduated arc A. C, the milled-head, by means of which the index mirror is moved. K, the adjusting key. E, the eye-hole through which the observation is taken; some instruments are provided with a dark glass, which can be slid into the place of E, for observations of the sun; others have a small telescope which fits in the same place. D, a magnifying glass for examining the vernier; it should always be placed directly over the latter, so that it may be viewed perpendicularly to the plane of the instrument. L and M, squares to which the key is applied when altering the adjustments.

FIG. 63.

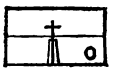


In most pocket sextants the arc is divided similarly to Fig. 62, and consists of 120° or 130°.

To measure the angle between two objects, hold the sextant in the left hand. Look through E and the opening O at the left hand object.

II. Turn C until the right hand object reflected from the index mirror, appears in the silvered part of the horizon glass coinciding with the left hand object, as shown in Fig. 64. The angle may then be read.

FIG. 64.



objects coinciding in the sextant by reflection.

There is a certain amount of knack in bringing the two images into contact in the sextant, the beginner should practise at first with two objects which are near each other.

Index Error.—Before or after measuring angles with the sextant its "index error" must be ascertained. Index error means that, owing to incorrect adjustment of the horizon glass, the point of the graduation from which on the arc angles are measured, is not zero.

To find the index error, select a well defined line, such as the edge of a chimney, 150 yards, or more, distant.* By means of the milled head C move the vernier so as to place the index near 0 of the arc. Now look through the eye-hole as explained, and bring the direct and the reflected images of the object into exact coincidence; if the vernier now read 0, there is no index error; otherwise note the reading to be applied to all observations as follows:—

It is seen that the graduations of the arc are continued some distance to the left of 0, this is called the "arc of excess" (Fig. 62). If the index points to this part, it is evident that all angles, being measured from this starting point, will be read by the vernier as too small. If the index points to the right of 0, the angles will be read as too large. The former is called index error "off" the arc, and is therefore to be added in correction of observations; the latter, index error "on," is to be substracted.

In reading the index error "off" on the arc of excess, it must be observed that the vernier being constructed to read in the same direction as the primary divisions (which in the case of the arc of excess are counted outwards from 0 *to the left*), the difference between the number of minutes read by the vernier and 30′, is noted for the correction, this is easier than counting the minutes from the right. This principle will be carried out also in noting the index error of large sextants, taking into consideration the construction of their verniers.

When the sextant is in proper adjustment, and there is no index error, the two mirrors are parallel when the index reads 0.

Should the right hand object be indistinct and difficult to see after reflection from the two mirrors, the sextant may be held upside down, and the left hand object brought to the right.

To observe a vertical angle. Hold the sextant in the right hand with its face to the left, and looking directly at the lower object, bring the upper object down to it by reflection, turning the milled head C with the left hand.

If the two objects be at different levels, as S and H, Fig. 65, it would be necessary, in order to bring their images together, to hold the sextant in the plane of the two objects, as shown. But the angle so measured would be oblique and greater than the required horizontal angle. To obviate this error, find by plumb-line, or by estimation, some object as C or D, in the same vertical plane as one and the same horizontal plane as the other object. Observe the angle between C and H, or between S and D.

Or, if the angular distance is small between two objects, which are at different levels, as E and S, Fig. 65, the angles between each of

* This distance is sufficient to render the "parallax" of the pocket sextant inappreciable. By parallax is meant a certain error to which all reflecting instruments are subject, arising from the observer's eye not being always in the same line as the index glass and the right hand object. The parallax is, in fact, *the angle subtended at the right hand object by the distance between the observer's eye and the centre of the index mirror.* The maximum of this being about an inch and a half in the pocket sextant, subtends only 1 minute at 143 yards, an inappreciable quantity. In large sextants the distance between the eye and the index mirror is some inches, and as telescopic power and a micrometer are used, a terrestrial object selected for finding the index error should be several hundred yards distant. The sun is generally observed for the purpose.

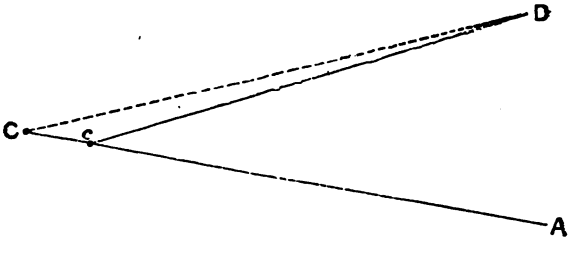
FIG. 65.

these and a third point, as D, at a distance of about 90° from them may be observed. The difference between these will be nearly the true horizontal angular distance of ES.

Most sextants will only measure angles up to about 110°. When the two objects are at a greater angular distance than the instrument will reflect; measure the angle between each of them and some intermediate point; the sum of these will be the required angle.

Should it happen in observing a triangulation, that the required angle ACD, Fig. 66, cannot be measured exactly *at*, but only *near* the station C, as, for instance, when the latter is a spire, or a chimney; the best plan is to measure the angle AcD at a convenient point *c in one of the lines*, and measure the distance Cc. This enables the angle to be protracted at a similar point in the plan; the method is only suitable for construction and not for calculation.

FIG. 66.



The method of placing oneself on the line between two distant points has been previously described.

Adjustment of the Pocket Sextant.

If the index error be considerable, it may be removed by adjustment, thus,

Set the index exactly at 0 on the arc.

Select a well defined point, such as a chimney-top, at some distance. First, observe whether the direct and reflected images are on the same level, if not, apply the key K to the square L, Fig. 63, and turn it until they are so. The effect of this correction is to set the horizon glass truly perpendicular to the plane of the instrument.

Next, if the reflected image overlaps that seen directly, or does not exactly cover it. Apply the key to the square M (Fig. 63), and turn it slowly until they coincide. The effect of this correction is to set the horizon glass parallel to the index mirror.

It is generally safer to note and apply the index error in correction of observations than to alter the adjustments.

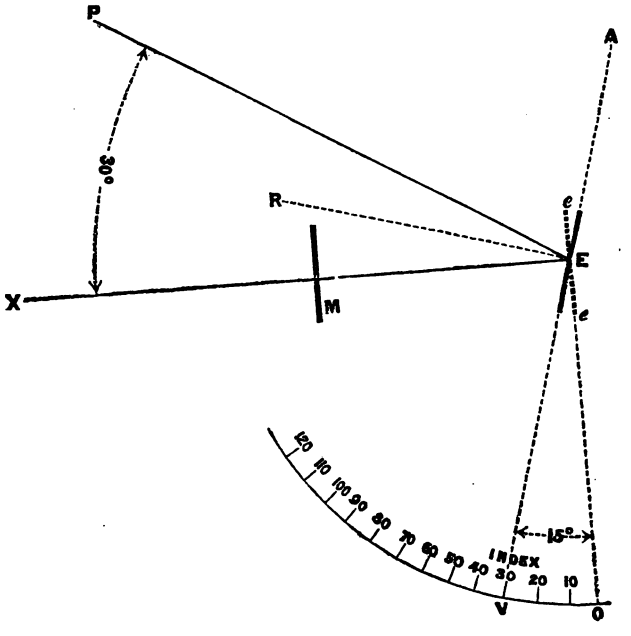
The advantages of the pocket sextant are its portability and accuracy; it can be used on horseback, or in any difficult position, such as the top of a tree, where it may be necessary to obtain an observation; it is not affected by local attraction, like the compass.

Its disadvantages are: It is not of general use, like the compass, but can only be employed for observing triangulation, determining heights and distances, and observing for latitude; it cannot be conveniently used for traversing, or the more ordinary operations of surveying; any difference of level between the points observed is liable to cause error.

THEORY OF THE SEXTANT.

It will be noticed that the actual angle contained between the graduations 0 and 120 on the arc of the sextant is only 60°. The reason for doubling the graduation may be thus demonstrated:—

FIG. 67.



Let P and X be the distant objects between which the angle PEX is measured; M the horizon glass of the sextant; E the movable index mirror which was in the position *ee*, parallel to M, when the index was at O; EX was then also perpendicular to *ee*.

Let ER be a perpendicular to E.

By a well-known principle in optics, the angle of incidence, PER, is equal to the angle of reflection, XER.

From the right angles XEO, REV take the common angle XEV, leaving XER = VEO. But PEX = 2 XER or VEO. Hence, the ray of light being reflected successively from two mirrors, the total angular deviation of the ray is double the angle of the inclination of the mirrors. Therefore VEO, though only 15°, is read 30° on the arc, Fig. 67.

For the sake of simplicity, the observer's eye is supposed to be at E in the figure.

Examples.

1. Construct a vernier to read thousands of a scale a foot long, divided into hundredths.
2. Construct a vernier to read 15″ on an arc graduated to 15′. One degree of the arc is an inch long; show half the length of the vernier.
3. The scale of inches attached to a mercurial barometer is divided into tenths; construct a vernier to read ·01 inch in the reverse direction to the numbering of the scale.
4. Each degree in the arc of a sextant is divided into three parts; the vernier consists of 40 parts; to what degree of accuracy does it read?

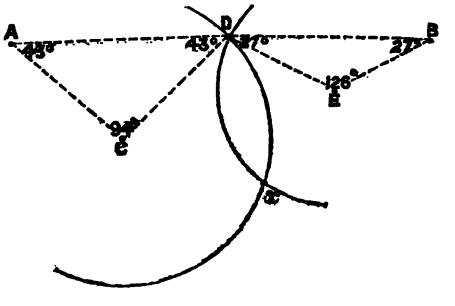
Interpolating with the Sextant.

Three points, the positions of which are already marked on the plan, must be visible, in order to find one's place in relation to them with the sextant.

The simplest way is by the method of "adjustment" described in connection with the plane table. That is to say, measure the angles *axb*, *bxc* (Fig. 19) with the sextant. Set off these angles with a protractor on a piece of tracing paper, and adjust this on the plan so that each of the three lines may pass through their respective points, A, B, C. Then prick off the position *x*, being the observer's place.

Another method is based on Euclid III, 20. That on the same base, or part of the circumference, the angle at the centre of the circle is double that at the circumference.

Fig. 68.



Let ADB be three visible points, the position of which is laid down. The angles at x are observed. AxD 47°, DxB 63°. To find x.

x is on the circumference of a circle, the angle at the centre of which, subtended by AD, is double 47°, or 94°.

To find this centre. The angles CAD + CDA = 180—94° = 86°; therefore each is 43°. Set off this angle at A and D, the intersection of the lines fixes C.

With centre C and radius CD describe an arc Dx.

In the same manner, to find the centre of the circle DxB. The angle DxB being 63°, the angle at the centre will be 63 × 2 = 126°. At D and B set off the angle $\frac{180—126}{2}$ = 27°, the intersection of the lines fixes the centre E.

With centre E and radius ED, describe an arc intersecting the first in the required point x.

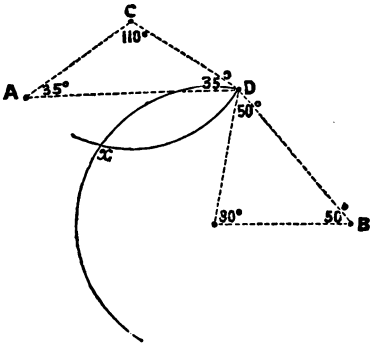
When the observed angle is greater than 90°, the centre of the circle will be at the far side of the line joining the points. To find it, make the calculation as above *for the supplement of the observed angle.*

For instance, A, D, B (Fig. 69), being the known points, the angle AxD 125° and DxB 40°.

To find the centre of the circle DxA, which will be at the far side of the line AD, the calculation will be made for 180°—125° = 55°; then the angle at the centre will be 55 × 2 = 110°, and each of the angles CAD, CDA $\frac{180—110}{2}$ = 35°.

The construction of the figure is shown in the diagram.

FIG. 69.



The accuracy of the construction depends on the arcs not intersecting each other at a very acute angle; when nearly parallel their point of intersection cannot be fixed with certainty.

This method is troublesome in the field, and, practically not so likely to lead to an accurate result as the method of adjustment, on account of the number of angles that must be protracted.

The problem is seldom used except for finding a ship's place with regard to points on the coast, which are shown on the chart; an instrument called a "station finder" is generally used for the purpose.

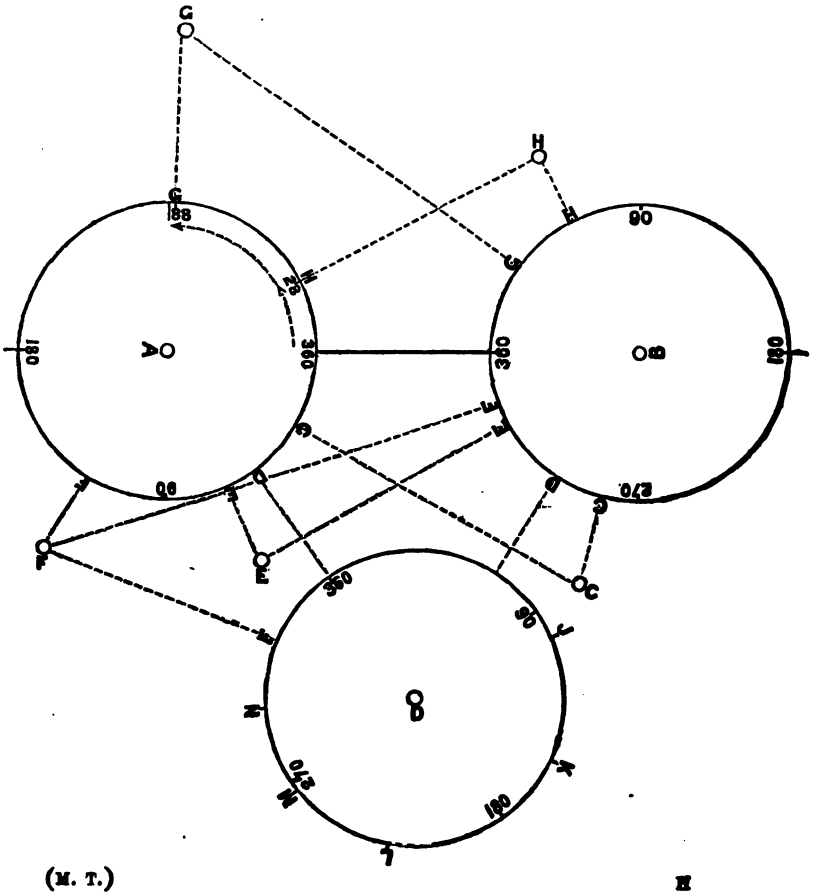
Plotting the angles observed with the sextant.

The accuracy to be obtained by using the small ivory protractor would be incommensurate with that of the observations made with the pocket sextant; in fact no protractor can really mark the direction of a line within 1 minute, a quantity smaller than the finest line that can be drawn on paper at the radius of a foot. An error of + or — 3 minutes would produce no perceptible alteration in the direction of a line laid down with the largest sized protractors, so that a pocket sextant measures with an accuracy that cannot be graphically reproduced.

The most accurate protractors are metal circles graduated like the arc of the sextant, and furnished with verniers, which can be set by slow motion screws to the required angle, the position of which is pricked on the paper by fine points. These are delicate instruments not likely to be much used in military surveying.

The large cardboard protractors are more commonly used for laying down the observations made with the pocket sextant. These vary in size from 1 foot to 18 inches diameter, some are graduated to $\frac{1}{4}$ degrees.

Fig. 70.



If a small circle about $\frac{1}{8}$th inch diameter be cut out of the cardboard at the centre, this can be adjusted to correspond with a point and its diameter (360—180°) with a line on paper, produced if necessary. In laying down a triangulation, this will be the "zero line" from, or to, which the angles were measured (*vide* Fig. 70).

Draw the base in a convenient part of the paper, and on it lay down the points A, B at their proper distance to scale.

The first round of angles was observed at A, noted thus—

Base AB, 1321 yards.

At A	From	B to C	29° 3′
	,,	B to D	53° 46′
	,,	B to E	65° 53′
	From	E to F	56° 9′
	,,	G to B	88° 12′.
	,,	H to B	28° 1′.

Adjust the protractor, as shown, on the zero line AB, its centre at A. Lay weights on it to keep it in position, and with a needle or a very finely pointed pencil prick off the position of all the angles, marking each point with its distinctive letter. Observe that the angle BAF being too large to be measured by the sextant, the angular distance of F *from E* was taken. To protract the angle, it is added to the angular distance of E from B, and the position of 122° 2′ (56° 9′ + 65° 53′) pricked off.

On the other side of the base the angles are recorded as "to" instead of "from" B, as the right hand object is brought to the left in observing with the sextant. This necessitates counting the degrees in the reverse direction on the protractor (see figure), unless, as is sometimes the case, the graduation is numbered both ways on it.

The protractor is now taken up, and the lines produced to an indefinite length through the marked points with a perfectly straight-edged ruler.

The next round of observations is noted thus—

At B	From	A to G	25° 10′
	,,	A to H	63° 2′
	,,	C to A	76° 50′
	,,	D to A	58° 3′
	,,	E to A	29° 28′
	,,	F to A	18° 17′.

The protractor is now adjusted at B, as shown, BA being the zero line. The position of the angles being pricked off, the lines are produced to intersect the relative lines drawn from A, the stations so determined are then surrounded by a small circle and lettered.

For the next round of angles observed at D, as noted below, the zero line was DA, and the protractor must be adjusted as shown—

At D	From	F to A	32° 6′
	,,	N to A	75° 54′
	,,	M to A	92° 37′
	,,	L to M	31° 7′
	,,	J to K	37° 3′.

The bearing of one of the sides of the triangles should be observed with a prismatic compass, so that the meridian may be shown

on the plan. To lay down the magnetic meridian, adjust the protractor at the point at which the observation was made, with the observed degree of bearing corresponding with the observed line. The diameter of the protractor is now N and S, and its position may be pricked off.

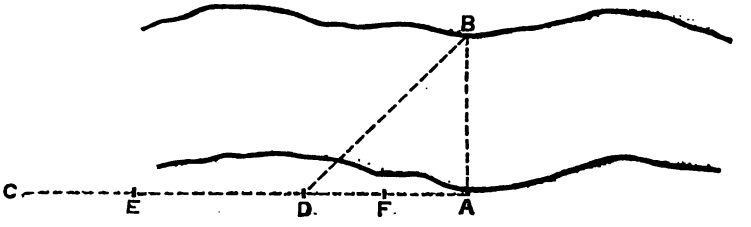
The sextant is very useful for setting off a perpendicular to a line in the field. Set the index at 90°; stand with one of the given points between the toes, and find some object, as distant as possible, belonging to the perpendicular (that is, coinciding by reflection in the horizon glass with the point marking the other end of the given line).

The distance of an inaccessible object can be quickly and easily found with the sextant.

Let A be a point on one bank of a river, B a bush or other object on the further bank. To find the width of the river. Find a distant object, C, perpendicular to AB, as described. Set the index at 45°, and move along AC until the point D is found where AB subtends this angle. Measure DA, equal to AB.

A table of tangents is given further on, showing a number of other convenient angles besides 45°. Not to burden the memory it will be sufficient to mention 26½° and 63½°.

Fig. 71.



If the index be set to the former, and the problem performed as before, the point F will be found; $AF = \frac{1}{2}\,AB$.

Using 63½°, the point E will be found; $EA = 2\,AB$.

By the same problem the heights of buildings on level ground may be found. Supposing AB (Fig. 71) to be the vertical wall of a building, and AC to be level ground. Make a mark on the wall at the height of the eye, set the index at 45°, and move back until this mark and the top of the building coincide in the horizon glass; the distance from this spot to the building is its height, minus the observer's height. The angles 26½° or 63½° may be used, as before, if more convenient than 45°.

SECTION XIV.

THE THEODOLITE.

The theodolite is used for the accurate measurement of horizontal and vertical angles.

The instrument is designated by the size of the horizontal plate H. Pl. IX, whence the ordinary pattern is known as the 5-inch theodolite.

This plate is divided into degrees and half degrees, read by the vernier to minutes, similar to Fig. 62.

Larger instruments are graduated more minutely.

When the instrument is levelled this plate has freedom of motion in a horizontal plane. It can be locked by the flat-headed screw L, beneath it, which clasps a collar round its axis; after being clamped, it can be moved slowly by the milled-headed screw *l*. These are called the lower clamping screw and lower micrometer, or slow motion screw. All the micrometers should be kept nearly "middled," or half way through their nuts.

On this plate revolves the vernier (or upper horizontal plate), the position of which is regulated by the upper clamping screw U and the upper micrometer *u*. At opposite sides are two verniers, by means of which is read the angular distance through which the upper part of the instrument has moved on the horizontal plate.

The vertical arc V moves, when the instrument has been levelled, in a vertical plane. Its clamping screw is indicated by C, and micrometer by *c*. One side of the vertical arc [not seen in the diagram] is graduated similarly to the horizontal plate, and its position is read by the fixed vernier Z. The other side of the arc is graduated to read the percentage of deduction to be made from distances measured on a slope, to reduce them to their true horizontal lengths (or difference of hypotheneuse and base).

The vertical arc carries the telescope, which is laid in two Y-shaped supports, the arms of which are tangential to cylindrical rings round the tube. It is held in position by clips hinged to the Y's. These can be opened when it is required to take off the telescope.

THE TELESCOPE.

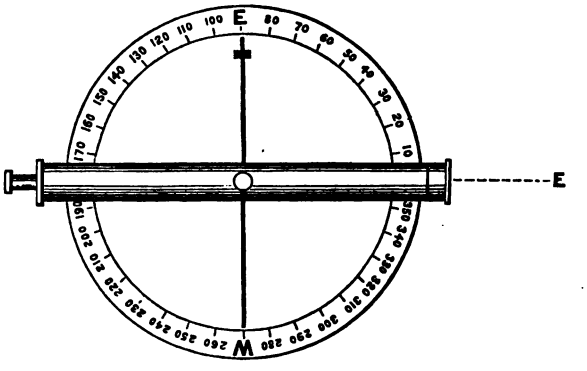
The telescope is provided with hairs, crossing at right angles to each other inside the tube. These hairs are placed in such a position as to be easily brought to the common focus of the object glass and the eye-glass.

To focus the telescope, first draw out the eyepiece until the hairs crossing in the centre of the tube can be seen clearly defined. Next turn the screw F, moving out the object glass until the distance is also in distinct vision. The cross hairs are focussed first, because the alteration of the object glass does not affect them. Much depends on the nice focussing of the cross hairs; to test it, the eye should be moved about the eyepiece from side to side; if the intersection of the

cross hairs changes position slightly with regard to the distant object, it shows the existence of "parallax," and the eyepiece must be moved in or out, until this is corrected.

The compass box is divided into 360°. The graduation is carried from right to left, contrary to that of the horizontal plate; so that when the telescope is directed on the distant object, the needle (remaining stationary) indicates its bearing or magnetic relation (Fig. 72).

FIG. 72.



There is a trigger outside the compass box, by which the needle may be lifted when not in use, so as to save the point of the pivot from wear.

The theodolite may be briefly described as having three movements, two horizontal and one vertical.

1st. The *absolute* horizontal movement of the whole head, controlled by the lower clamping and micrometer screws.

2nd. The movement of the vernier plate *relative* to the horizontal plate, regulated by the upper clamping and micrometer screws.

3rd. The vertical movement of the arc carrying the telescope, controlled by the vertical clamping and micrometer screws.

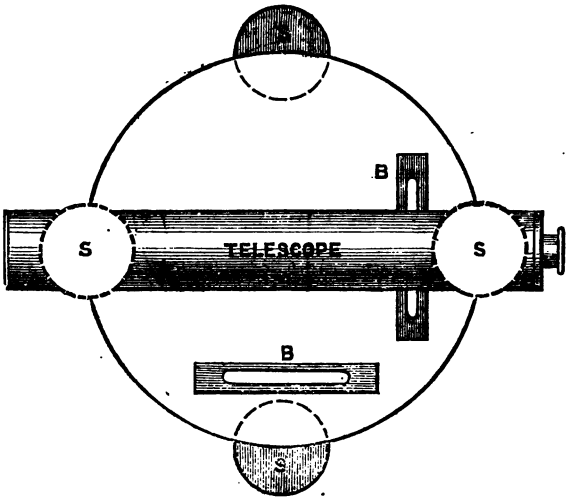
To set up the theodolite, grasp the instrument round the base SS in the left hand, and screw the tripod legs into it with the right. Or set up the tripod, unclamp the lower clamping screw, hold the instrument steady by the horizontal plate, and screw the lower part down on to the legs. The telescope should not be touched in revolving the theodolite. The strongest parts should be handled; for horizontal movement, the edge of the horizontal plate; for vertical movement, the vertical arc.

There will generally be a mark on the ground, over which the instrument is to be set up. The legs should be about a yard apart, and moved about until a pebble can be dropped from the vertex on to the mark, or a plumb line may be used for the purpose. The base plate P should be set fairly horizontal, else it will be found impossible to level the instrument. It is only possible to set up a theodolite on the side of a steep hill by placing two of the legs on the same level, and the third up hill. Each leg should be pressed firmly into the ground. In moving round the instrument, care must be taken to avoid kicking it, the legs of the theodolite must not be touched with the hand whilst observations are being taken.

The instrument is levelled by means of two pairs of conjugate screws, S. The effect of moving these screws is observed by the two

spirit levels B, on the horizontal plate. Loosen the lower clamping screw; revolve the head of the instrument, so as to place each of these spirit levels parallel to a pair of levelling screws, in order that they may be acted upon to the best advantage; this is the case when the vertical arc is in the same vertical plane as a pair of levelling screws. Work these, one up the other down, simultaneously, by turn-

FIG. 73.



ing both inwards, or both outwards. There is a good deal of knack in this operation; force must not be used, but the bottom of each screw must press sufficiently firmly on the base plate to keep the head from rocking. As soon as the bubble of this spirit level is nearly centred, operate upon the other level by the other pair of screws; this will probably disturb the first somewhat, and necessitate its being re-levelled.

The screws sometimes become jammed, so as to be difficult to move, either because one of the opposite pair has been overforced, in which case it should be eased; or because the base plate has not been placed sufficiently level in setting up the legs.

Instruments that have been handled by beginners are usually strained, and are difficult to level without applying an injurious degree of force. After a little practice the operation of levelling can be performed in about one minute.

MEASUREMENT OF HORIZONTAL ANGLES.

The theodolite being set up at the point of observation, and levelled, the three clamping screws are released, and the telescope focussed.

The angles are measured from left to right, corresponding with the direction in which the horizontal plate is numbered.

Place the index of the vernier, which is under the eyepiece of the telescope in coincidence with 0 of the horizontal plate.

Fix the plates together by the upper clamping screw. Examine by

the magnifying glass, and perfect the coincidence by the upper micrometer. It may here be remarked that, in using the magnifying glass, care must be taken to look *perpendicularly* at the graduation, the effect of viewing it obliquely might possibly occasion an error of some minutes.

Now turn the telescope (and the whole head of the instrument) on the object from which the angular distance of the rest is to be measured; clamp the lower clamping screw, and perfect the coincidence of the intersection of the cross hairs with the object by the lower micrometer. The lower screws are not to be touched again.

Before proceeding further, see that the vernier still reads 0 on the horizontal plate.

Loosen the upper clamping screw, and turn the telescope on the next object to the right: clamp and effect perfect coincidence by upper micrometer. Read the degrees and minutes by the same vernier which coincided with 0 on starting. The opposite vernier should also be read, and the mean of the number of minutes adopted.

A difference in the two readings may arise from incorrect graduation of the circle; or from the axes of the plates not being cylindrical, but elliptical, or slightly flattened; or from the axes not being concentric with the circles they carry (hence known as "eccentricity," very frequently caused by a fall); or from these plates not being exactly circular.

The telescope is, in like manner, turned on each object in succession, until the circle is completed. Lastly, on the original or "zero" point, when the vernier should be examined, to see that it has returned to 0. The weight of the observer on soft ground may have disarranged the original position of the instrument, or it may have "given" a little during the observation.

Should great accuracy be required, the round of angles may be again measured, this time commencing indifferently, from *any* part of the horizontal plate, such as 120° or 240°, instead of 0°. The true angular distances can be found by subtraction.

When only one angle is to be very accurately measured, a still more perfect method is to observe it *by repetition*. After having observed it in the usual manner, leave the two plates clamped together, and turn the whole head of the instrument back on the zero point, by the lower clamping and micrometer screws; now by the upper clamping and micrometer screws bisect the right hand object; the recorded angle will be twice the actual angle. The operation may be repeated three or four times; in this case it is only necessary to note *the last reading*, and divide it by the number of observations.

To observe the bearing.

To observe the bearing of an object, bisect it by the cross hairs, and read the degree in the compass box to which the needle points. If the telescope has been placed in the Ys, with its eyepiece over vernier A, the north end of the needle will point to the bearing. The legs should be lightly tapped, so as to shake the needle.

In consequence of the position of the needle and the width of its point compared with the graduation of the compass-box, the bearing can only be an approximation within 15 minutes or so. As the accuracy of any method of observing the bearing with the theodolite must wholly depend on observing the degree to which the needle

points at some stage of the operation, nothing would be really gained by employing any method, in which the apparent accuracy is founded on the superior graduation of the horizontal plate.

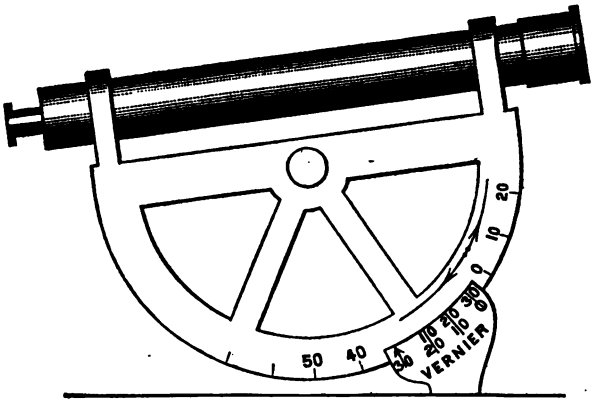
To observe vertical angles with reference to the horizontal plane.

Supposing the instrument to be in proper order, and all the adjustments correct, as presently described. The relative position of the two horizontal plates is immaterial, but they should be levelled.

Direct the cross hairs on the object by the vertical clamping and micrometer screws C and *c*, Plate IX, and read the angle indicated by the vernier Z on the arc.

This vernier is numbered from both ends, in order that it may be read *in the same direction as the graduation of the vertical arc, from* 0 *outwards.*

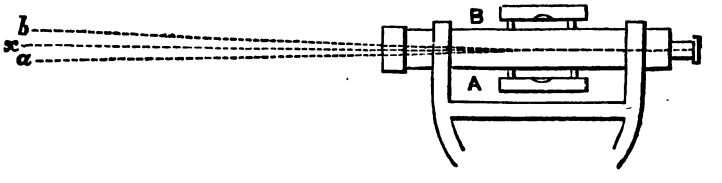
Fig. 74.



Thus in Fig. 74, the index of the vernier would be considered to be at its right end, and the minutes would be counted on the lower set of figures. Whereas, if the telescope were pointing downwards, the vernier would be read from left to right. No general rule can be laid down such as that for angles of elevation the vernier reads from left to right, and *vice versa;* for if the telescope, as shown in Fig. 74, were to be removed from the Ys and reversed, end for end, what had been an angle of elevation would be one of depression.

This would be sufficient for a rough observation, the instrument being in good order. For greater accuracy revolve the telescope in the Y's, so as to bring the spirit level uppermost; bisect the object

Fig. 75.



again, using micrometer *c;* note the angle, and take the mean of the two observations. This will eliminate "collimation error" (presently described).

For it is evident that with the ordinary position of the telescope A, Fig. 75, the line *a* will be as much below the true axial direction *x* as will be the line *b* above it, when the telescope is revolved to position B.

"Index error" (described further on) has also to be eliminated in observing verticle angles. Having noted the mean of the two readings, taken as above, open the clips, take out the telescope, and reverse it in the Y's; repeat the two observations with the spirit level above and below the telescope. Finally, adopt the mean of the two corrected readings.

Thus it is necessary to take four observations for a perfect measurement of the vertical angle, with reference to the horizontal plane of the instrument.

Properly speaking, this observation is subject to a further correction for refraction.

The parts of the Theodolite, and their adjustments.

The Diaphram.

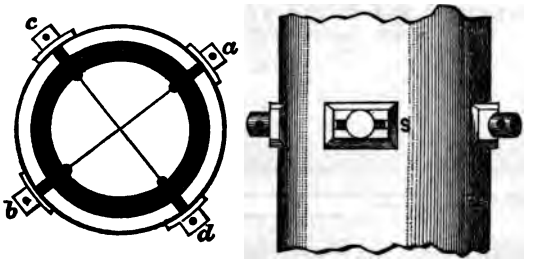
The optical or longitudinal axis of the telescope may be termed the "line of collimation."* The intersection of the cross hairs, marking the centre of the tube, should correspond exactly with this line.

The cross hairs are spiders' thread attached to a metal ring or diaphram, the position of which can be regulated in the tube of the telescope by means of four capstan headed screws, *a*, *b*, *c*, *d* (Fig. 76), which pass loosely through slots (S) in the tube, so as to allow the diaphram to be moved sideways as required.

These slots are each covered by a small plate to exclude dirt.

If it be wished to move the diaphram towards "*b*," loosen the screw "*a*" to give freedom of motion, then by screwing "*b*" into the diaphram, the latter is drawn towards that side of the tube, the slots at *cd*, allowing the sideward movement. Before screwing into

Fig. 76.



the tube, be careful to loosen the opposite screw, else the tube will be indented, or the diaphram strained. No force must be used, but all adjustments must be delicately effected.

* There are shades of difference between the meanings attached to this term by various authorities. For present purposes the above definition is sufficiently explicit.

To replace a hair when broken; remove the diaphram from the telescope, by taking out the screws *a*, *b*, *c*, *d*, and the eye-piece.

Wind up a spider by its thread, on a forked stick—its weight will be sufficient to stretch the web. Put a little glue or shell-lac on the diaphram, and apply the thread carefully to the marks which are cut on it, to show the diameter.

ADJUSTMENTS.

To examine the adjustment of the line of collimation,

Select a clearly defined distant point, or make a dot on the wall; direct the telescope on this—clamp all three clamping screws, and bring the intersection of the hairs exactly on the object by the upper micrometer *u* and the vertical micrometer *c*.

Now revolve the telescope in the Y's. If the intersection continues to coincide with the object, the adjustment is good, but if it deviates from it, correction is necessary. To effect this, revolve the telescope, so as to intersect the object by one of the hairs vertically; then revolve it a half circle, so as to reverse the position of the same hair—if it appear now at one side of the object, the diaphram must be moved also to the same side, because the real deflection is inverted in the telescope. Bring it thus half way towards the object, the other half by the micrometer *u*. Again revolve the telescope to its former position, and repeat the operation. Now proceed with the adjustment of the other hair in a similar manner.

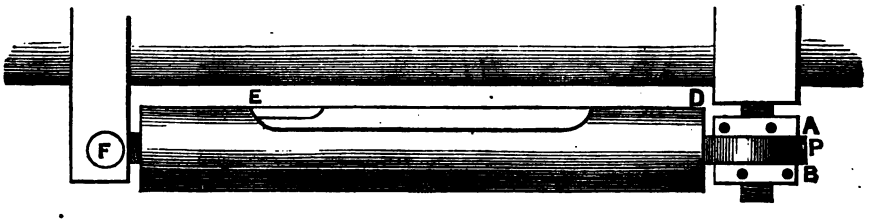
A few repetitions of each adjustment will probably be necessary before the error is wholly removed.

Adjustment of the Telescope Level.

The spirit level attached to the telescope must be parallel to the corrected line of collimation both horizontally and vertically. To examine the parallelism, open the clips which hold the telescope in its Ys, bring the bubble to the centre by the vertical clamping and micrometer screws, and clamp firmly. Remove the telescope carefully from the Ys, without disturbing the arc, replace it, but reversed "end for end" (that is, with the eyepiece, where the object glass was); if the bubble returns to the centre, no adjustment is required.

For adjustment, this spirit level may be raised or depressed at one end by two nuts, A and B, Fig. 77, following each other on a screw

FIG. 77.



and holding between them P, which projects from the case of the spirit level. If the bubble on replacing the telescope in the Y's, be found at the E end, then D requires raising. The upper nut A must be run up the screw to give room, and is followed by B until the bubble is brought *halfway to the centre*, the remaining half by the micrometer *c*.

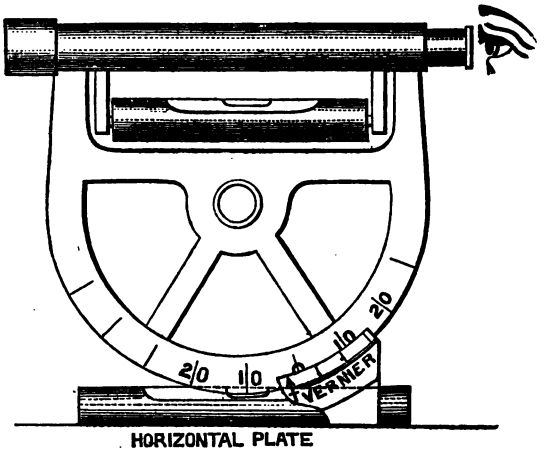
Now again lift the telescope and change it, end for end; if necessary repeat the operation until the reversal of the telescope produces no effect on the bubble. To examine its vertical parallelism to the line of collimation, revolve the telescope a little (about $\frac{1}{8}$th of a revolution) when the bubble will, if the adjustment be incorrect, move from the centre. To correct it, there are two adjusting screws (F, Fig. 77, and a similar screw on the opposite side) by means of which that end of the spirit level may be moved sideways.

Index Error.

Index error implies that when the bubble is brought to the centre of a properly adjusted spirit level as above described, the index of the vertical vernier does not point to 0 on the vertical arc, the upper horizontal plate having been levelled.

It is usual to read and take note of the amount of this error, and apply it in correction of observations. A little consideration will show how it is to be applied; for instance, if it be found that the vernier instead of 0, reads 10 minutes beneath 0, as represented Fig. 78, it is evident that all angles of depression will read 10 minutes

FIG. 78.



too much, and angles of elevation 10 minutes *too little*, so that this quantity must be applied in correction accordingly. But if the telescope happens to be oppositely placed in the Y's, end for end, then 10 minutes must be deducted from angles of elevation, and *vice versa*.

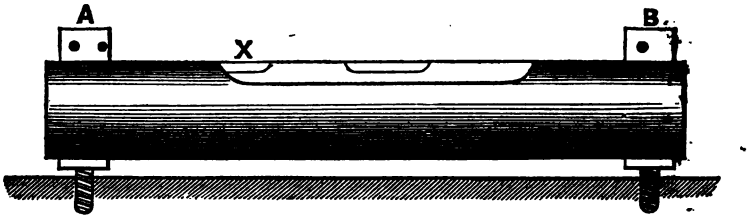
To find the index error more exactly, intersect a well-defined object by the cross hairs: note the vertical arc reading. Open the clips, reverse the telescope end for end in the Y's, and repeat the observation. Half the difference between the readings will be the index error.

The correction of index error may be effected by loosening the screws which fasten the vernier, and shifting it sideways as required, then tightening them again. The sideward motion is permitted by slots, cut in the vernier, through which the screws pass loosely.

Adjustment of the Vernier Plate Levels.

The levels on the upper horizontal or vernier plate are usually fastened to it by capstan-headed screws at each end.

Fig. 79.



To examine the adjustment. Place one of the spirit levels in position to be acted upon by a conjugate pair of levelling screws, and bring the bubble to the centre in the usual way. Now revolve the vernier plate, so as to place the same spirit level *at the opposite side of the circle;* if the bubble does not return to the centre, adjustment is necessary. For instance, if the bubble be at X, it shows that that end of the tube is too high, therefore turn the screw A *into* the plate, which will lower it, or screw B *out* of the plate to raise the other end. Bring the bubble thus half way to the centre of the tube, the remaining half by the levelling screws.

Revolve the plate again to its first position, and repeat the adjusting process if required. It will be observed that by revolving the plate the spirit level is changed "end for end."

Now examine the other spirit level and correct it in a similar manner.

When in proper adjustment, the bubbles will remain centered during a complete revolution of the horizontal plates of the instrument.

Vertical Movement.

The vertical arc should move only in a vertical plane when the instrument is levelled. To test this, observe if the intersection of the cross hairs follows a plumb-line hung from a height.

The necessary correction can only be effected by an instrument maker.

If the levelling screws be all run upwards, it will be found that the head of the instrument is loose, and has a certain amount of play, being connected with the base plate by a ball and socket joint, permitting its being levelled, although the base plate may not have been set up truly horizontal (Fig. 80).

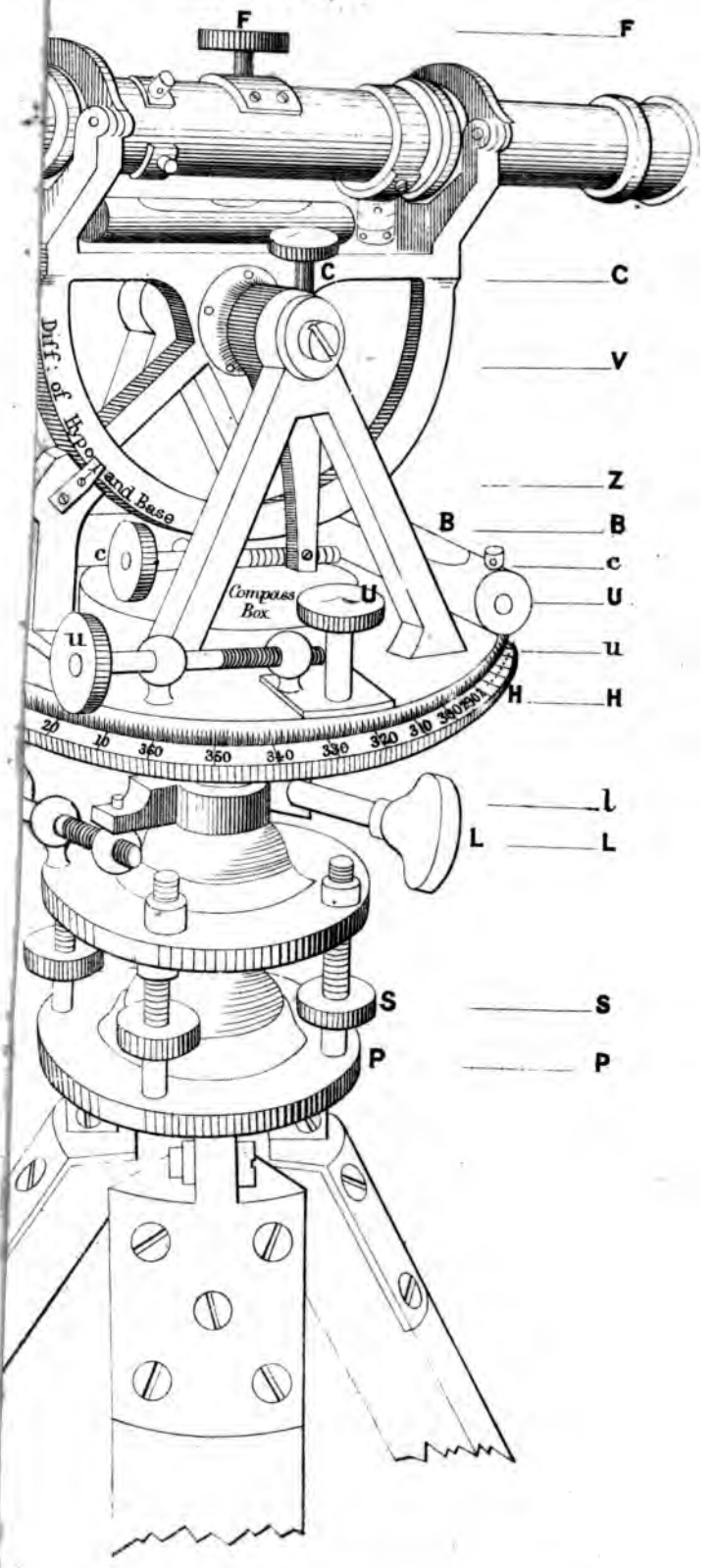
The hinges of the legs work loose in time, and require tightening up with a turnscrew, as do also the wood screws.

The adjustments described should not be practised with an instrument to be used for accurate work.

The operator should act deliberately, and be certain of the effect of the alteration he proposes before proceeding with it.

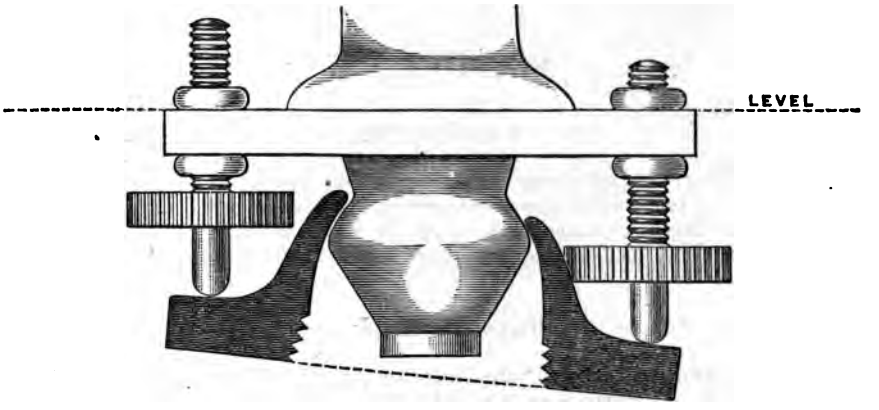
Consideration will show, that by a little ingenuity, the theodolite might still be used were any two of the three spirit levels broken.

PLATE IX.



DANGERFIELD LITH 22 BEDFORD ST COVENT GARDEN

FIG. 80.



The theodolite above described is of the ordinary type commonly used. Improvements have been made in later patterns; 5-inch instruments are now accurately graduated to read 30 seconds or less; the levelling is effected by three independent, instead of four, conjugate screws; lines engraved on glass are substituted for the spider hairs, and in many other respects the mechanism is improved.

SECTION XV.

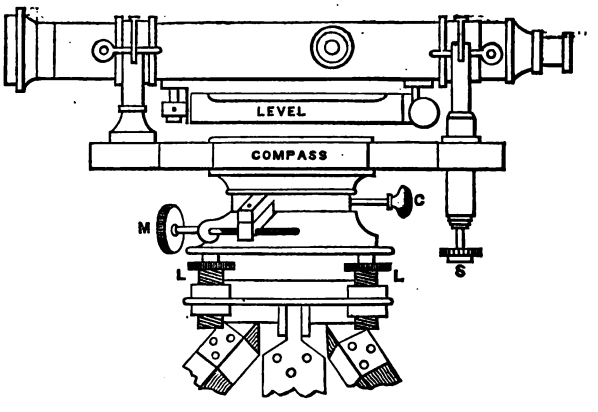
LEVELLING.

Levelling may be described as surveying in a vertical plane, it's object being to measure the difference of level between points, in connection with the construction of roads, railways, canals, &c.; or to obtain the data for drawing correct sections of the ground.

The Spirit Level.

Of several patterns of this instrument it will be sufficient to describe the Y spirit level, the telescope of which rests in supports similar to the theodolite; it is levelled by means of two pairs of conjugate screws L, which have their bearings in the base plate, whilst

Fig. 81.



their heads act against the upper plate. The upper plate of the instrument is connected with the lower by a ball and socket, as in the theodolite, and the telescope can be turned in any direction, and its position adjusted by the clamping screw C and micrometer M.

There are usually two vertical cross hairs, and one horizontal, attached to a diaphram, which may be adjusted in the usual manner.

The spirit level is longer and more sensitive than that of the theodolite, the arrangements for adjusting its parallelism to the line of collimation of the telescope are similar to that instrument.

A magnetic needle in a graduated compass-box is set on the bar which carries the Ys—by its means the direction of the observations can be registered.

The only adjustment that differs from those already described is that by which the telescope is set at right angles to the vertical axis, so that when levelled it may move in a horizontal plane only. This is done by means of the screw S, which raises or lowers one of the Y

supports. To examine the adjustment, place the telescope over a pair of levelling screws and bring the bubble into the centre of its run by their means; now turn the telescope round, so as to reverse the spirit level "end for end." If the bubble does not return to the centre, bring it there, half by the screw S, and half by the base levelling screws.

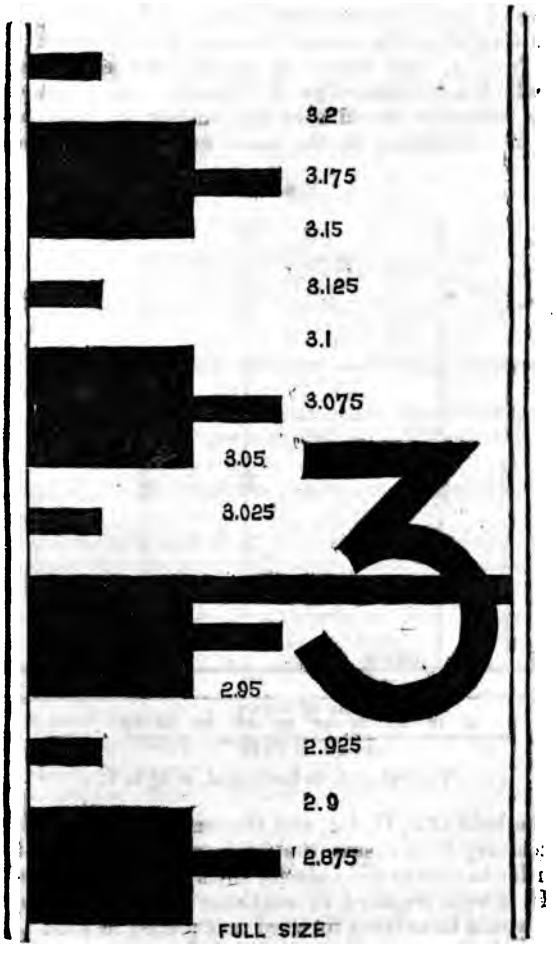
Again reverse the telescope, and repeat the adjustment until correct. Next turn the telescope at right angles to this position, and level it by the pair of levelling screws now under it. The bubble should now remain centered, whatever the direction of the telescope may be.

For accurate levelling the mean of the readings should be noted, observed with the spirit level above and below the telescope.

The Levelling Staves.

There is a great variety of these, but all are divided into feet and

Fig. 82.



decimals of feet, and are usually 14 feet long, closing telescopically in three joints.

The method of reading the numbers on the pattern (Fig. 82) is shown.

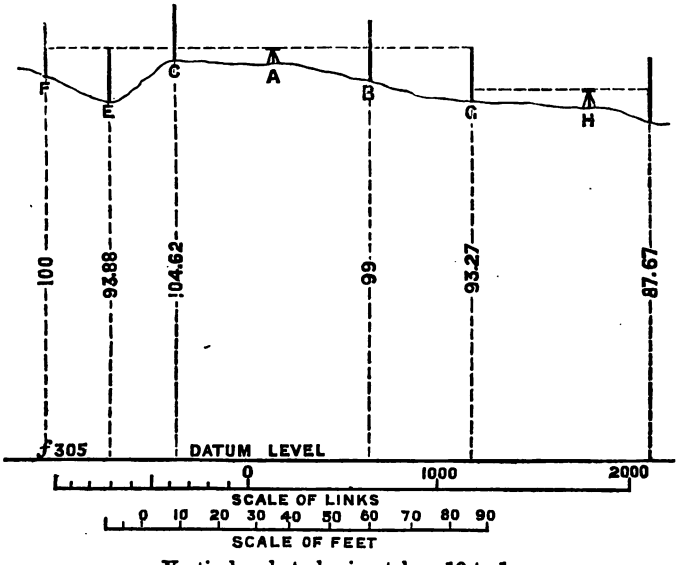
The distance at which these marks can be read, varies with the state of the weather; under favourable circumstances they are visible up to 250 yards, with an inverting eye-piece.

The staff is to be held perfectly upright—in fine reading, the staff bearer should sway it slowly to and from the observer, when the lowest reading will be correct.

Suppose the spirit level to be set up at A (Fig. 83), directed on the levelling staff at B, and the figure noted which is cut by the horizontal hair. This figure would be the difference of level between A and B, minus the height of the telescope above the ground (which might be measured and deducted). If the distance between the points were under 300 or 400 yards, the correction for curvature and refraction presently described would be inappreciable.

Suppose another staff were held at C and the telescope directed on it, the difference between the readings of B and C would evidently be the difference of level between these points, *independently of the height of the spirit level above the ground, common to both*, and if C and B be equidistant from A, they would be equally affected by curvature and refraction, which might therefore be ignored. Any error of collimation in the telescope would also be common to both observations, and would be eliminated in the same manner. The levelling staff

FIG. 83.



Vertical scale to horizontal, as 13 to 1.

might also be held at F, G, &c., and the readings noted. It would then only be necessary to measure the horizontal distance between these points in order to obtain the data for drawing a correct section of the ground. If it were required to continue the levelling beyond G, the spirit level would be carried forward and placed in such a position H,

and at such a height that it might intersect some part of the staff at G, care being taken not to alter the position of the foot of the latter meantime, but merely to turn it with its face towards the spirit level.

In the operation represented (Fig. 83), the levelling commencing at F and proceeding forward to the right, F would be called the back staff, G the forward staff, and E, C and B would be intermediate.

On setting up the level at H, G would become the back staff, those to its right would be intermediate, and the last place at which the staff could be held, before it would be necessary to carry the spirit level on, would be the forward staff.

The spirit level must be placed with judgment in such a position as to command a good view of the ground over which the section passes; it need not of course be placed *on* the line, but it should be nearly equidistant between the places of the back and forward staves.

The following form of levelling field book will be found generally convenient:—

Station.	Bearing.	Back reading.	Intermediate.	Forward.	Rise.	Fall.	Reduced level.	Distance.	Remarks.
A	—	6·52	—	—	—	—	100·00	—	Assumed.
	—	—	12·64	—	—	6·12	93·88	305	
	—	—	1·98	—	4·54	—	104·54	642	
	—	—	7·25	—	—	0·73	98·27	1680	
	—	—	—	13·25	—	6·73	93·27	2193	
H	—	3·15	—	—	—	—	—	—	
	—	—	6·75	—	—	3·60	89·67	—	
	—	—	&c.	—	—	—	&c.	—	

When the back reading is greater than the forward, the latter must evidently be the higher ground, and the difference is entered in the column "rise," and *vice versâ*.

The distance of all intermediate points are measured *inclusive* from the starting point.

As to the column "reduced levels," it is usual to assume a datum level, or imaginary line to which all the vertical measurements are referred. The entries in this column show the heights with regard to this line. Some even number of hundreds of feet is generally taken, and it is convenient that the datum level should be lower than any part of the section, so that all the measurements may be taken above it, as shown in Fig. 83.

In the Ordnance Survey of England the datum to which all the altitudes refer is mean high water at Liverpool. In military surveys inland there would be no particular object in referring to sea level.

The datum in the above register is assumed at 100, and in the column "reduced levels" the height of each point is noted with reference to this, obtained by addition to, or subtraction from, the "reduced level" of the back staff.

Thus all the "reduced levels" of station A are simply the entry "rise" or "fall" added to, or subtracted from, 100.

In the observations belonging to station H, the "rise" or "fall" would be added to or subtracted from 93·27, the "reduced level" of the back staff at G.

The columns "rise," "fall," and "reduced level," may be filled in at leisure.

The staves are called "back" and "forward" in reference to their *relation to each other* on the section line, not as regards the spirit level, which might be before or behind both.

In measuring the distances, the deduction due to the degree of slope should be made before entering them in the register. When the slope is less than 3 or 4 degrees the deduction is so small that it may usually be disregarded. The simplest way of obtaining the true horizontal distances is by means of the Watkin clinometer, as explained in connection with measurement of a base.

Should the object of the operation be merely to find the total difference of level between two places, this is obtained by taking the difference between the sum of the "rises" and the sum of the "falls" of the back and forward readings only, omitting the intermediate readings.

In extensive levelling operations it is usual to leave permanent marks called "bench marks," on objects such as mile stones and walls, and to record for future reference the exact height of each mark. In the later Ordnance Survey sheets the levels of the various bench marks are figured with their height in feet and decimals above mean high water at Liverpool.

The bench marks in England are of this pattern, , cut about half an inch deep.

To draw the Section.

Draw a horizontal line to represent the *datum level;* on this set off the horizontal distances between the points, to scale.

In the example, Fig. 83, F was the starting point, so that the distances of the points belonging to station A, measured inclusively from F to G, are set off as shown, from *f* on the datum line.

To obtain the position of the surface of the ground or form of the section, erect perpendiculars at each of these points, and set off on them the lengths taken from the column "reduced level." Join these points F, E, C, &c.

The vertical scale is generally assumed much larger than the horizontal, so as to show clearly the undulations of the ground.

Preparing a level site.

It is sometimes required to level a site for some purpose on uneven ground. For this operation prepare a number of stout pickets of various lengths. Set up the spirit level near the place, and at such a height that the telescope may command a plane passing close above the highest part of the site. Let an assistant hammer a short picket flush with the ground at the highest part, then hold a pole perpendicularly on the top of the head of this picket. Direct the horizontal

hair of the spirit level on this pole, and let the assistant make a mark on it at the corresponding height. The assistant now hammers in pickets at different places as required, until the horizontal hair intersects the mark on the pole held on the head of each. All these are now on the same level, and workmen can be directed to excavate or fill up to a similar distance below the heads of each.

If good judgment be used, the height decided upon will be such that the cutting will equal the filling.

The levelling staff may be used instead of a pole, the height being noted at which the horizontal hair intersects it.

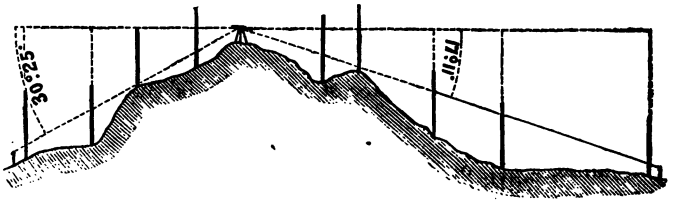
Levelling with the Theodolite.

The theodolite may be used for levelling when a high degree of accuracy is not required. The adjustment of its telescope spirit level must be perfect.

The telescope should be always revolved in the Y's, and the mean of the readings on the staff noted, so as to eliminate collimation error.

Sections of ground may be taken with the theodolite more expeditiously, though less accurately than in the manner described with the regular spirit level, Thus—

Fig. 84.



Let the theodolite be set up as shown in the figure, its telescope directed parallel to the general slope of the hill. Observe this vertical angle with all precautions for accuracy proper to the operation.

Keeping the telescope clamped in this position, note the successive readings of a levelling staff held by an assistant at the various points which will best define the irregularities of the section; the height of the theodolite and the horizontal distance between these points being measured, a section can be drawn thus.

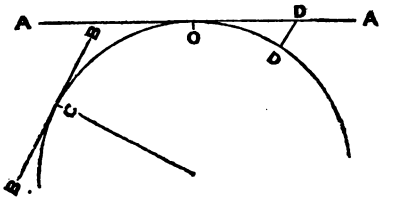
Draw the horizontal line passing through the telescope. Protract the observed angle of inclination (as shown in the figure). On the horizontal line set off the measured distances to scale. Draw perpendiculars from these to the hypothenusal line. Beneath the points thus found, set off the staff readings, being the level of the ground where the foot of the staff stood for each observation.

Should the staff be so distant that the markings are illegible, a system of signals can be agreed upon, so that the assistant can move a visible mark along the face of the staff until signalled correct, the assistant can then note the reading.

Curvature and Refraction.

The plane AA, Fig. 85, or the "apparent level" observed with the spirit level, is a tangent to the earth's surface at the point O, as is the plane BB at the point C, being perpendicular to the earth's semi-

Fig. 85.



diameter. Two or more places are said to be on the same level when they are equally distant from the centre of the earth, as D O C.

Hence the true level is not a plane, but a curve concentric with the general figure of the earth. The quantity DD, the difference between the apparent and the true level, at the distance OD is known as the "curvature," the excess of the secant of the arc of distance above the radius of the earth.

By the property of the circle, curvature is equal to the square of the distance between the places, divided by the earth's diameter, 7916 miles.

The curvature at the distance of one mile is then $\frac{1}{7916}$ mile = 8·004 inches.

At 2 miles, $\frac{4}{7916}$ or 32·016 inches.

At 10 miles, $\frac{100}{7916}$ or 66·7 feet. So that, rejecting the decimal quantity, *the curvature in feet is seen to be equal to $\frac{2}{3}$rds of the square of the distance in miles*, an easily remembered formula for calculating the amount at any distance.

Refraction.—The course of a ray of light is diverted downwards in an increasing curve in passing from above through the denser atmosphere near the earth's surface. Its effect known as "refraction," is that a distant object appears to be higher than it really is. The nearer the object is to the horizon, the greater the refraction; thus the sun may be seen above the horizon after it has really sunk beneath it, the maximum horizontal refraction being nearly 34 minutes.

The causes which produce refraction such as heat, cold, humidity, exhalations, &c., being variable, no certain rule for its correction can be adopted; in astronomy, tables are used giving the mean refraction for various degrees of elevation.

In levelling operations, a rule that will nearly correct for horizontal refraction, is; deduct $\frac{1}{8}$th from the curvature found as explained.

Thus, the approximate combined correction for curvature and refraction for 10 miles is $66 - \frac{66}{8} = 57\frac{3}{4}$ feet.

The effect of curvature is evidently to make objects appear less

elevated above the true level than they really are; or, in the case of angles of depression, more depressed beneath the true level than they really are, so that in the former case the correction must be added, in the latter subtracted.

Refraction is always a minus quantity.

Correction for Curvature and Refraction up to 12 *miles.*

Miles reduced to feet.		Correction in feet for curvature and refraction.	Miles reduced to feet.		Correction in feet for curvature and refraction.
Miles.	Feet.		Miles.	Feet.	
	1,000	0·02		4,500	0·40
¼	1,320	0·03	1	5,280	0·55
	1,600	0·05		6,000	0·71
	2,000	0·07	1¼	6,600	0·86
½	2,640	0·14		7,000	0·96
	3,000	0·18	1½	7,920	1·25
¾	3,960	0·31		8,500	1·42
1¾	9,240	1·70	5¾	30,360	18·36
2	10,560	2·22	6	31,680	20·00
	11,000	2·40	6¼	33,100	21·70
2¼	11,880	2·81	6½	34,320	23·47
2½	13,200	3·47	6¾	35,640	25·31
2¾	14,520	4·20	7	36,960	27·22
3	15,840	5·00	7¼	38,280	29·20
	16,000	5·10	7½	39,600	31·25
	16,500	5·26	7¾	40,920	33·36
3¼	17,160	5·40	8	42,240	35·55
3½	18,480	6·80	8¼	43,560	37·81
	19,000	7·16	8½	44,880	40·14
3¾	19,800	7·81	8¾	46,200	42·53
4	21,120	8·89	9	47,520	45·00
4¼	22,440	10·03	9¼	48,840	47·53
4½	23,760	11·25	9½	50,160	50·14
4¾	25,080	12·53	9¾	51,480	52·81
5	26,400	13·89	10	52,800	55·55
5¼	27,720	15·31	11	58,080	67·22
5½	29,040	16·80	12	63,360	80·00

SECTION XVI.

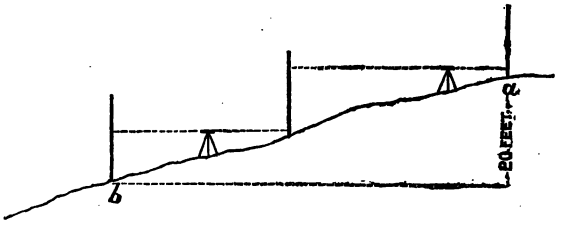
CONTOURING.

The true contours of ground may be required for military purposes in connection with road making, fortification, inundations, &c.

The vertical interval at which the contours are to be traced, having been decided, the first operation will be to plant a set of pickets or "initial points" at this difference of level, on a section line termed the "initial line."

The position of the highest or the lowest initial point will be marked by a pole, and another pole, or flag, will be placed in the distance, marking the direction chosen for the initial line (usually on a watershed).

FIG. 86.



Let the vertical interval be 20 feet, and the first initial point placed at the top of the slope *a*, Fig. 86, the levelling staff is held here, and the spirit level or theodolite placed so far down the slope that the telescope, when levelled, may intersect it near the ground. The reading is noted, say 1·5. The staff is now carried down hill as far as possible, without passing beneath the plane of the telescope; the reading being now, say 13·5, the staff is below *a*, 13·5 — 1·5 = 12 feet.

A further fall of 8 feet is required to complete the 20 feet; the foot of the levelling staff is kept in its present place, but its face is turned round; the spirit level is again carried downhill, placed below it, and the staff read, say, 2·3. The staff is now moved down the slope until the telescope reads 2·3 + 8 = 10·3. This point being found, is marked by a picket, the initial point *b*.

The same process is repeated until all the initial points have been placed.

To avoid error the staff readings should be registered, thus:—

Required difference of level 20 feet.

Back reading.	Forward reading.	Difference.	Remarks.
1·5 2·3	13·5 10·3	12 8 — 20	Initial point *b*.
2·8 1·7	12·9 11·6	10·1 9·9 — 20·	Initial point *c*.
&c.	&c.	&c.	

When the position of the initial points is to be measured from the foot of the slope, upwards, the spirit level, or theodolite, is placed on each occasion so much *above* the Staff that the telescope may intersect it near the top.

The initial points being fixed, the direction of the initial line is observed either with reference to some other known line, or independently, by its bearing. The horizontal distances between the initial points are then measured with the chain, the deductions due to slope being made.

The levelling of the first contour is now proceeded with. A position is found for the spirit level, within half a mile or so, whence it will command an uninterrupted view of the ground on which the contour will lie. This place must be at such a height that the telescope, when levelled, may intersect the levelling staff held at the initial point.

The staff now used should have a horizontal piece, or vane, which can be moved up or down upon it, and firmly fixed. A pole with a similar mark visible at long distances will answer the purpose, as the numbers on the staff are no longer required.

Signals will have to be agreed upon by which the observer can communicate with the staff-bearer, as they will seldom be within hearing of each other.

The telescope being levelled and directed on the pole, the observer signals to the assistant to slide the mark along it until it corresponds with the intersection of the cross-hairs. It is firmly fixed in this position.

The staff-bearer now moves along the contour, placing pickets at the points which best define its shape; that is to say, at the extremes of the salient and re-entering bends. When he judges himself to be near the proper level, he will hold the pole perpendicularly and look to the observer at the spirit level, who will signal to him to move up or down hill until the mark again coincides with the cross-hairs, then the foot of the pole will be on the same level as the initial point.

Should the contour pass round the shoulder of a hill, out of sight of the telescope, the instrument must be moved to a fresh position. The pole is held at the last picket fixed; the spirit level, or theodolite, carried to the new position, set up, and the telescope directed on the pole. The observer now signals to the staff-bearer to move the mark

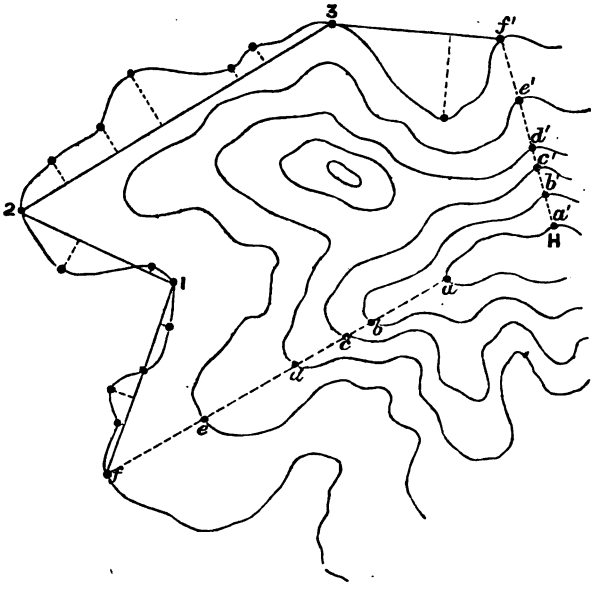
and fix it again on the pole at the intersection of the cross-hairs of the telescope, as at starting; the picketing of the contour is then proceeded with, as before.

In contouring a small piece of ground, the theodolite may be placed so near as to discern the figures on the ordinary levelling staff. In this case the figure which the telescope intersects on the staff placed at the initial point will be noted, and in placing the contour pickets the staff bearer will be signalled to move up or down hill, until this figure is again intersected.

The number of pickets required will depend entirely on the intricacy of the ground and the size of the features.

The surveying of the contour pickets is performed in the manner

FIG. 87.

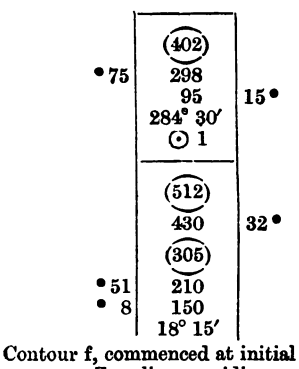


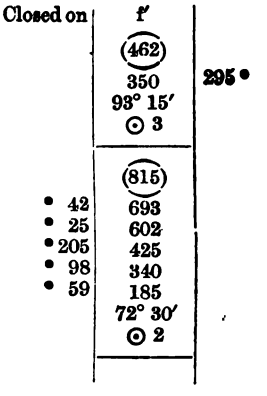
employed for all irregular lines. A traverse line in the general direction of the contour is observed, from which perpendicular offsets are taken to the pickets.

Thus, contour *f*, Fig. 87, is commenced at the initial point, and surveyed by the traverse lines 1, 2, 3, with offsets to the pickets, as shown dotted.

As a check on the accuracy of the work, both as regards the levels and the survey of the pickets, a second initial line H*f'* may be taken; H being placed by observation at the same level as *a*, and the process of placing the initial points *b'*, *c'*, *d'*, *e'*, *f'*, being carried out independently of those on the other initial line. The distance and direction of H from *a*, also the direction of H*f'*, and the distances between the initial points on this line are accurately surveyed. Then when setting out the contour on the ground, the staff will (if there be no mistake) arrive at the level of the initial point marked on the second initial line. Also when plotting the contour on paper, the accuracy with which the traverse closes on this point will test the work.

The field book entries for contour *f* would be as follows. When a contour picket occurs *on* the traverse line, the entry should be surrounded by a circle to distinguish it.





Contour f, commenced at initial point.
Zero line, meridian.
Measurements in links.

It is advisable to level and picket only as much as can be surveyed before leaving the ground for the day.

Any peculiarities of form which will not be sufficiently explained by the position of the pickets should be sketched on the spot.

A favourite German surveying apparatus, the "kippregel," is peculiarly adapted to the operation of contouring. Not only can the contour be levelled, but also its plan drawn by the observer without leaving the instrument. It is not even necessary to mark the contour by pickets.

SECTION XVII.

TRIGONOMETRICAL SURVEYING.

The principles which should govern the arrangement of a triangulation have been stated as regards sketching small portions of country extending over a few miles.

The theodolite is employed for larger operations, such as carrying a chain of triangulation through an unknown country (as from the sea coast of Abyssinia to Magdala), or for any regular surveying operation in which a high degree of accuracy is required.

It has been seen that even the pocket sextant gives a minuteness of accuracy that cannot really be reproduced by construction with any protractor; and of all sketching apparatus the highest degree of accuracy in triangulation could probably be obtained with the plane table and sighted ruler.

But in more extensive operations the lengths of the sides of the triangles are calculated, and are independent of the mere mechanical accuracy with which they can be shown on paper; or rather, by means of this knowledge the stations can be fixed with an accuracy that could not be otherwise approached.

Referring to Fig. 16, the principle of rapidly extending the length of the base without incurring the risk of inaccuracy will be kept in view: and the system of determining stations by building a series of small triangles on each other will be avoided. The original base (measured in the case under consideration near the sea coast, and probably only a mile or so in length) can by a few judicious and careful observations be accurately transferred to neighbouring heights five or six miles apart. From these heights may be observed points, such as well marked pinnacles of rock, ten or twelve miles inland, and their distances can be calculated. These, when reached during the advance of the column, become observatories whence the triangulation is extended further inland.

Let AB, Fig. 16, be the base.—By measuring the angles CAB, DAB, CBA, DBA, the data are obtained for calculating the lengths of AC, AD, BC, BD. Now two independent values of the new base CD can be obtained, AC, AD being known, and the contained angle CAD measured; also BC, BD, and the contained angle CBD.

If these values of CD practically agree, it may be safely adopted as the base for the calculation of two values of EF.

The conditions which afford the greatest probability of accuracy are—first, that the angle opposite the base be less than a right angle; second, that the angles adjacent to the base be nearly equal.

30° is considered the smallest angle which the base should subtend at the distant point, in trigonometrical surveying; any smaller angle would constitute an "ill-conditioned triangle." The intersection at 60° is, as has been explained, the best.

In triangulation, as in all surveying operations, the principle to be observed is to "work from the whole to a part;" in other words, to enter on no small operations early in the work; therefore the size of the

triangles should be as large as the nature of the country will permit. From the principal trigonometrical stations thus determined, will be observed "secondary stations," conspicuous natural, or artificial points, scattered throughout the district.

These stations will be pricked off on the sketch sheets of the persons employed in "filling in" the details of the ground by plane table or compass; so that, instead of measuring a base and determining points therefrom (as they would do in performing independent sketches), they refer the position of their principal points to these trigonometrical stations, either using them as the ends of a base, or interpolating their position from them during the course of the traversing.

In arranging the triangulation, it must be remembered that the principal points must be suitable for "observing stations," where the theodolite can be set up on the spot itself, and that church spires, chimneys, &c., being unsuitable for this purpose, are merely fixed as secondary stations useful for "filling in" the survey, but not for extending the triangulation.

The principal trigonometrical stations will be poles, &c., erected on hill tops or open ground commanding an extensive view. These can be removed temporarily to allow the theodolite to be set up vertically over the hole in which they stood; or a tripod of poles may be erected surmounted by an object such as a gabion covered with canvas painted black or white, in contrast to the background; this will be visible for many miles, and the thoodolite can be set up vertically beneath the apex of the poles, without removing them; or a pole, with a disc nailed at the end, may be fastened projecting above the top of a tree.

More refined methods of exhibiting the point to a distant observer are often employed. By means of the "heliostat," the rays of the sun can be reflected by a mirror from a distant station towards the observing station, rendering the former visible under favourable circumstances at 100 miles or more; the ordinary flashing signal apparatus may be available.

A powerful light, such as the lime light, can be distinctly seen at many miles distance on a clear night. By this means most of the important observations have been made in great operations.

All three angles of the principal triangles should be observed.* In secondary triangles it will usually be sufficient to measure the base angles carefully, and to assume the third or vertical angle to be their supplement.

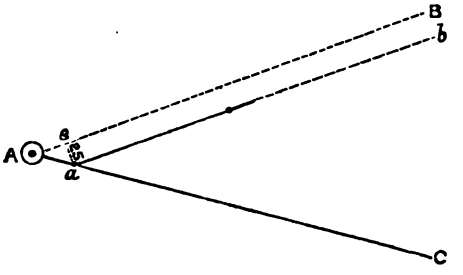
Should it be necessary to measure an angle at an inaccessible station, such as a church spire, an expedient may be adopted somewhat similar to that employed for the sextant (Fig. 66) under similar circumstances, differing in that the angle observed must be the *actual angle at the inaccessible station.*

Find the lines AB, AC (Fig. 88) by means of straight rods laid on the ground, as already explained. Set up the theodolite at a convenient point *a*, on one of the lines; measure the perpendicular distance *ae* from the other line. Place a visible mark at *b*, making B*b* = *ae*. Observe the angle *ba*C = BAC.

* With large theodolites the "spherical excess" can be detected, the minute quantity by which the sum of the three angles exceeds 180°, in consequence of the earth being not a plane, but a sphere. This quantity is too small to be detected by ordinary theodolites.

Another minute correction ignored in military surveying, is the reduction of the sides of the triangles to their lengths as measured at the level of the sea.

FIG. 88.



The observation of the triangulation may be noted in the following form:—

At	From (zero point).	To	1st.	2nd.	3rd.	Mean.	Vertical angle.	Remarks.
Cairn A.	D	B	48° 54′	53′	52′	48° 53′ 0″		Flagstaff, spire, &c.
	„	E	76 14	14	13	76 13 40		
	„	F	174 2	3	2	174 2 20		
	„	G	222 31	34	33	222 33 0		
		H	230 6	6	7	230 6 20		
		D	360 0	0	0			
Flag X.	A	E	32 7	6	7	32 40 0		
	„	M	49 20	20	20	49 20 0		
	„	N	100 45	46	44	100 45 0		
	„	O	172 9	8	10	172 9 0		
		L	205 3	3	3	205 3 0		
		A	360 0	0	0			
	&c.	&c.						

In the second and third repetitions of the readings, the number of minutes only need be noted, as shown.

The vertical angles are noted when it is desired to calculate the difference of level between the two stations; in this case the height of the theodolite should be measured and curvature and refraction taken into consideration.

*Reduction to the Centre.**

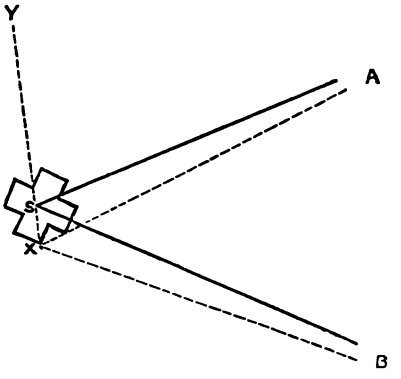
If a number of observations are to be made at an inaccessible station, it may be advisable to set up the theodolite as near as possible to it, and to correct each of the angles observed at this spot, so as to obtain its value as if observed at the station. The operation is hence termed "reduction to the centre."

Let S be a spire at which a round of angles is to be observed, of which ASB is one; and let X be the nearest point at which the theodolite can be set up, known as the "Satellite Station." Here the round of angles is measured from the zero line XS.

The required angle is ASB, the observed angle AXB, and the differences of direction of A and B, as observed from X and from S, are the small angles SAX, SBX. For let XS be produced towards Y,

* "Reduction to the centre" is a problem very rarely employed in practice.

FIG. 89.



then the exterior angle ASY is equal to the two interior and opposite angles (Euc. 1, 32) AXS, SAX. The latter must then be found and added as the correction.

Again, as regards B, the angle YSB = SXB + SBX.

Then YSB − YSA will be the central angle ASB required.

To find the angle SAX, the data are the sides SX, AS, and the angle SXA.

log. SX + Ar. Co. log. AS + log. sin. SXA = log. sin. SAX.

Of the known sides SX is measured on the ground. AS is found either approximately by construction, or by calculation, (being so much longer than SX an approximation is sufficient). To find it by calculation, the length AB must be known, and the angles ABS, BAS observed.

Calculation of the Triangles.

The lengths of the sides are calculated in most cases from the data of two observed angles and the length of a side known. The required sides are proportional to the sines of the opposite angles. Thus, if the known side AB be 3086 links, the angle BAD 76° 14′, ABD 54° 53′, and ADB 48° 53′. To find AD—

Sin. D : Sin. B :: AD : AB

by logarithims, log. b = log. d + log. sin. B − log. sin. D

= 3·489396 + 9·912744 − 9·877010 = log. b.

When a large number of calculations are to be made, the computation will be simplified by tabulating it in the following form, using the log cosecant of the angle opposite the known side, instead of the log sine, so that addition only is required.

Δ	Angles.	Angles.	Logarithmic computation.	Distance.	Side.	Remarks.
ABD			3·489396	3086	AB	Base.
	ADB	48° 53′	0·122990	—	—	Cosecant.
	ABD	54° 53′	9·912744	—	—	Sine.
	BAD	76° 14′	9·987341	—	—	Sine.
			3·525130	3351	AD	
			3·599727	3979	BD	

The quantities not required in the computation may be covered with a piece of paper; the first two logarithms are common to both sides.

The only other case likely to occur is that in which two sides and the contained angle are known, and the third side is required.

The sum of the two sides is to their difference, as the tangent of half the sum of the angles at the base, to the tangent of half their difference.

Let the known sides be f 1076·53 and e 2846·39, and B the contained angle 150° 7′, to find the other quantities.

The sum of the angles opposite the given sides will be 180—150°7′ = 29° 3′, and half their sum = 14° 31′ 30″.

Ar. co. log. $(e+f)$ 3922·92	=	6·406347
log. $(e-f)$ 1769·86	=	3·247936
log. tan. $\frac{1}{2}$ (E + F) 14° 31′ 30″	=	9·413205
log. tan. $\frac{1}{2}$ (E − F) 6° 39′ 46″	=	9·067491

Hence E = 21° 11′ 16″, and F = 7° 51′ 44.″

To find the required side b.

log. cosec. E 21° 11′ 16	=	10·441982
log sin. B 150° 57′	=	9·686254
log. e 2846·39	=	3·454296
log. b 3824·12	=	3·582532

SECTION XVIII.

MEASUREMENT OF THE BASE.

This operation must be performed with great care, as on it depends the accurate knowledge of every subsequent calculated dimension.

In military surveying, the base will usually be measured with the 66-foot chain, consisting of 100 links joined by small rings. This length has been adopted on account of its convenience both for superficial and for linear measurement. An acre contains 10 square chains, a mile 80 linear.

At each 10 links in the chain, from both ends to the centre, there is a brass label with one, two, three, and four tongues; the centre, or 50 links, is marked by a round label. Thus the number of links measured can be counted at a glance without the necessity of reckoning them from either end of the chain.

Distances measured with the chain are noted in links, the link being from centre to centre of the small rings joining them.

The length of the chain is liable to alteration; lengthening by the opening of the joints when it is overstrained; shortening by the bending of the long links. It should be tested from time to time by a standard chain not used in the field, or the standard length may be marked on a pavement for the purpose. If the chain is found to be incorrect after a day's work, the percentage of correction to be applied to the measurements should be found. If the chain is too long, the distances measured by it must have been recorded as too short, and *vice versa*. Thus, supposing that the chain be found 1·5 inches too long, 0·19 of a link per cent. should be added to the measurements.

The chain is used by two men, the leader and the follower; the leader is provided with 10 iron arrows; he walks in the required direction until nearly at the chain's length from the starting point, when the follower halts him and dresses him in the proper direction by beckoning him to the right or left; allows him to draw the chain a foot or so too far, and then pulls it steadily back, until the outside of the handle touches the starting point, the chain being kept at a fair tension without jerking. The leader now sticks an arrow in the ground, *touching the inside* of the handle at his end; or if the ground is too hard, he scratches a cross upon it and lays the arrow alongside. To avoid displacing the arrow, the leader should give the chain a cast to one side each time it is drawn forward, so that it may run clear.

The leader having placed his arrow, calls "all right," when the follower picks up the arrow at his end and the chain is drawn forwards. There must always be an arrow in the ground, except at the time, as follows:—

When the chain leader has expended the 10 arrows, 1,000 links is noted in the field book; another chain is then measured out, the leader places his foot on the handle, and waits until the follower comes up and returns him the 10 arrows. He counts them to see that none are missing, *plants one inside the handle*,* and they start afresh.

* It is at this stage that mistakes are commonly made.

On arriving at the end of the measurement, the leader passes the point until the full length of the chain is drawn out, and does not leave his place until the total number of links has been registered; the number of times the arrows have changed hands, as thousands of links; the number of arrows in the follower's possession (including that marking his end of the chain) as hundreds; and the number of links between the follower and the point, as tens and units.

All these details must be systematically carried out. It is better that the chaining should be done by the two men superintended by the surveyor, and that no other person should assist.

It is evident that measurements made on sloping ground must be reduced, according to the steepness, to their true horizontal lengths. The following table gives the reductions to be made in links from each hundred measured, according to the degree of slope :—

Degree.	Reduction.	Degree.	Reduction.
1	0·015	11	1·8
2	0·06	12	2·2
3	0·14	13	2·6
4	0·25	14	3·0
5	0·4	15	3·4
6	0·6	16	3·9
7	0·7	17	4·4
8	1·0	18	4·9
9	1·2	19	5·4
10	1·5	20	6·0

It would be out of character with the operation to observe with the theodolite changes of slope, occurring every 20 or 30 yards, in order to apply the above reductions accurately. The most practical method in military surveying is to measure the inclination with the Watkin clinometer for each chain, taking the observation to the head of the chain leader. The chain should be pulled tight enough to prevent it from dipping into slight hollows in the ground, or may be supported in the centre.

The degree of slope for each chain should be noted on the spot; the deductions may be filled in subsequently, and their sum subtracted from the measured length; thus :—

Register of Slopes for each Chain.

Slope.	Deduction.	Slope.	Deduction.	Slope.	Deduction.
4°	0·25	1°	0·01	3°	0·14
5	0·4	2	0·06	2	0·06
3	0·14	6	0·6	8	1·0
1	0·01	6	0·6	8	1·0
0	0·0	5	0·4	8	1·0
0	0·0	10	1·5	4	0·25
0	0·0	10	1·5	2	0·06
3	0·14	12	2·2	6	0·6
2	0·06	5	0·4	0	0·0
4	0·25	3	0·14	1	0·01
6.	0·6	9	1·2	1	0·01
10	1·5	2	0·06	2	0·06
3	0·14	0	0·0	0	0·0
0	0·0	0	0·0	0	0·0
0	0·0	0	0·0	1	0·01
				5	0·4
	3·49		8·67		
					4·60
					8·67
					3·49
			Total deduction		16·76

Measured length .. .. 4600· links.
16·76

True horizontal distance .. 4583·24

When there is time, the base may be measured two or three times, and the mean adopted. The shortest measurement made with the chain is usually the most correct.

The surveyor walks behind the chain follower and sees that the alignment is properly kept; that the arrows are properly planted; the end of the chain adjusted to them; the chain kept at good tension, so as not to dip into hollows of the ground; that no mistake is made at the time the arrows are returned by the follower to the leader; notes these as thousands of links; and counts the hundreds and tens on arriving at the end of the measurement.

He also observes the slope for each chain and registers it as above.

In measuring a base on undulating ground, the objects marking its ends will be lost sight of in the valleys, so that the line must be "ranged" or marked out by flags in such places.

Care must be taken to notice that there are no knots or "kinks" in the chain whilst it is being used.

After a triangulation has been carried over a large district, and the sides calculated, a check on the accuracy of the whole series is obtained, by measuring one of these sides and comparing its actual with its calculated length. The side to which this test is applied is termed a "base of verification."

SECTION XIX.

CONSTRUCTION OF THE TRIANGULATION.

To construct the triangulation, or determine the position of the stations from the calculated length of lines joining them to other known points. These lengths are taken as radii with which arcs are drawn, the intersection of the arcs being the spot required.

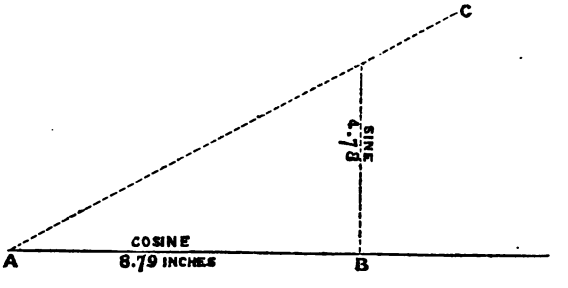
Ordinary compasses would be unsuitable for the purpose, both on account of the flexibility of the legs and the shortness of their span. The proper instrument is the beam compass, which consists of a wooden bar, with the required scale drawn on it; it is fitted with sliding verniers for minute adjustment, and needle points which coincide with the indices, by means of which the required length is marked on the paper.

If the original base has been extended in the manner described, one of the longest calculated sides should be first laid down, the larger triangles first drawn, and the smaller derived from them. Thus the original base may be one of the last sides laid down in plan.

Should beam compasses not be available, the stations may be first determined by the angles, laid down with the protractor, as described in connection with the pocket sextant; the lengths of the sides should be then tested, and the position of the trigonometrical points corrected by a carefully constructed scale, drawn on the edge of a slip of the same paper as the plan. The pencil used should have a very fine point. When accurately placed, the trigonometrical points should be marked by an ink dot, surrounded by a circle, within which no lines must be produced.

The advantage of the paper scale is that it expands and contracts in the same proportion as the plan with changes in the humidity of the air, which may cause a considerable alteration in the length of paper.*

FIG. 90.



The most accurate manner of setting off an angle, next to that of the intersection of arcs, is by means of the natural sines and cosines

* I have found as great a difference as 30 yards in 1,000, between the 6 inches to a mile scale on the ivory protractor and on the Ordnance Survey Sheet, due to contraction of the latter.

given for every degree of the quadrant in the accompanying table. There being no limit to the lengths which may be adopted, this method is particularly suitable for the construction of large triangles.

A Table of Natural Sines, Cosines, Tangents, Cotangents, Secants, and Cosecants, to every Degree of the Quadrant.

Deg.	Sines.	Cosines.	Tangents.	Cotangents.	Secants.	Cosecants.	
0	00000	1·00000	00000	Infinite.	1·00000	Infinite.	90
1	01745	99985	01745	57·2900	1·00015	57·2987	89
2	03490	99939	03492	28·6363	1·00061	28·6537	88
3	05234	99863	05241	19·0811	1·00137	19·1073	87
4	06976	99756	06993	14·3007	1·00244	14·3356	86
5	08716	99619	08749	11·4301	1·00382	11·4737	85
6	10453	99452	10510	9·51236	1·00551	9·56677	84
7	12187	99255	12278	8·14435	1·00751	8·20551	83
8	13917	99027	14054	7·11537	1·00983	7·18530	82
9	15643	98769	15838	6·31375	1·01246	6·39245	81
10	17365	98481	17633	5·67128	1·01543	5·75877	80
11	19081	98163	19438	5·14455	1·01872	5·24084	79
12	20791	97815	21256	4·70463	1·02234	4·80973	78
13	22495	97437	23087	4·33148	1·02630	4·44541	77
14	24192	97030	24933	4·01078	1·03061	4·13356	76
15	25882	96593	26795	3·73205	1·03528	3·86370	75
16	27564	96126	28675	3·48741	1·04030	3·62796	74
17	29237	95630	30573	3·27085	1·04569	3·42030	73
18	30902	95106	32492	3·07768	1·05146	3·23607	72
19	32557	94552	34433	2·90421	1·05762	3·07155	71
20	34202	93969	36397	2·74748	1·06418	2·92380	70
21	35837	93358	38386	2·60509	1·07114	2·79043	69
22	37461	92718	40403	2·47509	1·07853	2·66947	68
23	39073	92050	42447	2·35585	1·08636	2·55930	67
24	40674	91355	44523	2·24604	1·09464	2·45859	66
25	42262	90631	46631	2·14451	1·10338	2·36620	65
26	43837	89879	48773	2·05030	1·11260	2·28117	64
27	45319	89101	50952	1·96261	1·12233	2·20269	63
28	46947	88295	53171	1·88073	1·13257	2·13005	62
29	48481	87462	55431	1·80405	1·14335	2·06266	61
30	50000	86603	57735	1·73205	1·15470	2·00000	60
31	51504	85717	60086	1·66428	1·16663	1·94160	59
32	52992	84805	62487	1·60033	1·17918	1·88708	58
33	54464	83867	64941	1·53986	1·19236	1·83608	57
34	55919	82904	67451	1·48256	1·20622	1·78829	56
35	57358	81915	70021	1·42815	1·22077	1·74345	55
36	58778	80902	72654	1·37638	1·23607	1·70130	54
37	60181	79863	75355	1·32704	1·25214	1·66164	53
38	61566	78801	78122	1·27994	1·26902	1·62427	52
39	62932	77715	80978	1·23490	1·28676	1·58902	51
40	64279	76604	83910	1·19175	1·30541	1·55572	50
41	65606	75471	86929	1·15037	1·32501	1·52425	49
42	66913	74314	90040	1·11061	1·34563	1·49448	48
43	68200	73135	93251	1·07237	1·36733	1·46628	47
44	69466	71934	96569	1·03553	1·39016	1·43956	46
45	70711	70711	1·00000	1·00000	1·41421	1·41421	45
	Cosines.	Sines.	Cotangents.	Tangents.	Cosecants.	Secants.	Deg.

The lengths may be taken off any scale of equal parts, such as the marquois scales. Let it be required to set off 28° 34′ at the point A, in the line AB. The table shows 883 for the cosine, and 469 for the sine of 28°. The sine and cosine of the 34′ may be found by proportion, making the numbers respectively 879 and 478, as explained below.

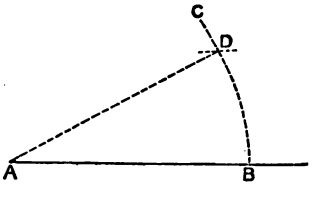
Take on AB the length of the cosine 8·79 inches, measured by the edge of the artificial scale 30 of the marquois scales, or by any other scale of inches and tenths applied to the line (the second place of decimals may be taken by estimation). At this point erect a perpendicular, on which measure 4·78 inches; the required line will pass through this point.

8·79 is taken as 8·83 minus 4 ($\frac{34}{60}$ths of the difference between cosines 28° and 29°). 4·78 is taken as $\frac{34}{60}$ths of the difference between the sines of 28° and 29° added to that of the former. The first three figures of the sines, &c., are sufficient. The proportional quantity for cosines must be deducted, for sines added to that of the given degree.

These dimensions might be doubled were it desirable, for the sake of greater constructive accuracy, and if the plan would contain them.

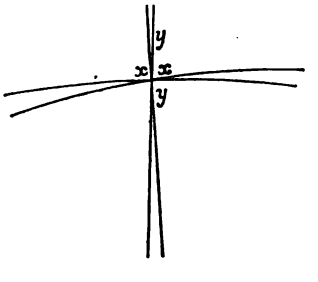
With the scale of chords engraved on many protractors, accuracy within about 15 minutes may be obtained. Describe an arc BC with a radius of 60°, taken on the scale of chords. On this arc set off the length of the chord BD of the given angle DAB, taken from the same scale.

FIG. 91.



It is impossible to determine accurately the point of contact of arcs or right lines, which intersect very obliquely. In the former the *distance* of the station, or length of radius is certain, and the uncertainty is as regards the *direction*. For instance, to take an extreme case (Fig. 92), the station might be anywhere in *xx*.

FIG. 92.



In the intersection of right lines, the uncertainty is as regards the *distance* at which the contact takes place; thus the station might be anywhere in *yy*. A combination of the two will give the best results.

SECTION XX.

TRAVERSING.

The principles of traversing have been explained as regards the compass and the plane table, and need not be repeated. The only difference, when traversing with the theodolite, is in the manner of observing the angles, which is performed so as to utilise the accuracy of the instrument.

Supposing firstly, that the traverse is to be performed in connection with stations which have been accurately determined by triangulation. The theodolite is set up at one of these with the object of traversing up to, and "closing" on another, so as to check the accuracy of the work.

The vernier plate will be clamped with its index reading 0 on the lower horizontal plate; the magnetic needle released; the whole head of the instrument turned so as to intersect another visible station with the cross hairs, the lower clamping and micrometer screws being used to perfect the intersection.

Every forward angle in the traverse will be measured with reference to this station, the imaginary line connecting it with the present place of the theodolite is termed the "zero line."

The degree in the compass box to which the magnetic needle points, is registered as the bearing of the zero line.

The points at which the theodolite is set up to observe the forward angles will be here referred to, for clearness, by the sign ⊙.

An assistant takes forward a pole or flag, and sets it at the first ⊙. The upper clamping screw is released, and the telescope directed on this by the upper micrometer. The foot of the pole, or the lowest part visible, should be observed, so that if it is not quite upright, the accuracy of the observation may not be affected. The reading of the same vernier that was set to 0 is now noted in the field book as the forward angle.

The plates are left clamped together in this position, and the theodolite is carried forward and set up at ⊙ 1, exactly over the hole in which the pole stood; this is tested by a plumb line, or by dropping a pebble from underneath the head of the instrument.

The lower clamping screw *only* is now released for the purpose of levelling the theodolite. The telescope is directed on the starting point by the lower clamping and micrometer screws. Before unclamping the upper horizontal plate, the vernier is examined, and the reading compared with the field book, to ascertain that its position has not altered; it is then released, and the telescope directed on the next forward ⊙ by the upper clamping and micrometer screws. The forward angle is now read by the vernier opposite to that by which the previous forward angle was read; the reason for this will be presently explained.

It should have been observed that the forward angle is the last registered at each ⊙, and that the direction of conspicuous objects at some distance, which are to be fixed by intersection, are first noted. The direction of branch roads are also noted.

The distance from ⊙ to ⊙ is chained, and perpendicular offsets measured, as previously explained, with the offset rod or the tape. The field book will be kept in the manner shown for the prismatic compass.

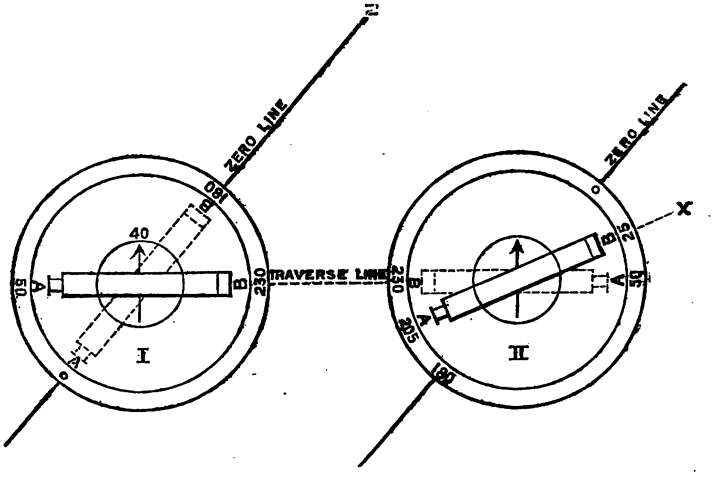
To recapitulate the operation at each ⊙—

1. Set up over the ⊙. Release lower clamping screw. Level. Direct the telescope on back ⊙ by lower clamping and micrometer screws.
2. Examine the agreement of the vernier with the last forward angle noted.
3. Release upper plate, and direct the telescope on forward ⊙ by upper clamping and micrometer screws.

Remark that in the first operation only the lower screws are touched; in the last only the upper.

This system, known as the "back angle system," may be thus explained.

FIG. 83.



Let I be a plan of the theodolite set up at the starting point, from which the traverse is carried through II towards ×. The line to station Z is selected as the zero line.

When the telescope (as shown dotted) was directed on the zero line, the degree 40, to which the needle pointed was registered as its bearing.

The upper plate being unclamped and the telescope directed on ⊙ II, the vernier A reads 50°, noted as the forward angle.

measurements	forward
50°	

Commenced at Station I. Zero line Z, bearing 40°.

The theodolite being carried forward and set up at ⊙ II, with the telescope (dotted) directed on ⊙ I; the whole head of the instrument has been turned round 180°, so that the diameter 0—180 has been again set to correspond with the zero line, from which therefore the next forward angle can be measured, as at starting. It is also evident that if the vernier A or B be turned to 0 on the horizontal plate, one of the ends of the magnetic needle will again point to 40° in the compass box.

The upper clamping screw having been loosened, and the telescope directed on the forward ⊙ ×, vernier A reads 205°, vernier B 25°. Both express the same line, but produced in opposite directions. The reversal of the horizontal plate has placed 0 where 180 was, at the first ⊙, so that vernier B must now be read. When the theodolite is set up at ⊙×, the position of its diameter 205—25° will again agree with the line AX, but transposed 180°, so that the next forward angle will be read by vernier A, and so on alternately.

If the surveyor consider the general direction of the zero line, he can have no doubt as to the vernier which is to be read; for if the general direction of the road be to it's right, the forward angles must be under 180°; if to its left, more than 180°.

As the 0—180 diameter is on each occasion set to correspond with the zero line, a check on the work may be applied whilst taking the forward angle, by putting the vernier at 0, and noticing whether one end of the magnetic needle points, as at starting, to 40°. In applying this test the surveyor must bear in mind the errors inherent in the needle, and must not be misled into making any alteration of the plates on seeing that the needle deviates by 1° or 2° from 40°. This deviation may be due to local attraction, either at the present place or the starting point. If the needle points wide of 40°, he would suspect an error, take the theodolite back one or two ⊙'s, and re-observe the forward angles.

A cross should be cut in the ground, or the position of the ⊙'s otherwise marked, so that the work may be re-examined in case it does not close satisfactorily on paper.

On leaving off work for the day, the positions of the last two ⊙'s should be well marked, that the traverse may be resumed with certainty.

After closing on a station, it is as well to set up the theodolite there, and measure the angle contained between the last back ⊙ and some other trigonometrical point; this provides the means of plotting the traverse back from this station, as well as from the other, if required.

A good surveyor will set the theodolite so nearly level by the position of the legs, that a few touches of the levelling screws only will be necessary at each ⊙, and the observation of the forward angles with the theodolite will not be a much slower process than with the prismatic compass.

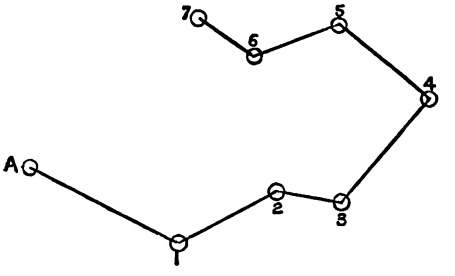
The position of the ⊙'s must be chosen with judgment, so that the traverse may be executed with the smallest possible number of observations.

Traversing, independent of triangulation.

In any traverse, all the forward angles should be with reference to one zero line. It has been shown how the traverse is connected with a triangulation by adopting one of the sides of the triangles as the

zero line. When independent of a triangulation, *the first traverse line* is usually adopted as the zero line.

FIG. 94.



For example, in traversing from A to ⊙7, the theodolite would be first set up, not at A, but at ⊙1; the 0—180 diameter directed on A; it's bearing noted, and the first forward angle measured would be 120° between A and ⊙2. The back angle system would then be followed, as already described, so that the 0—180 diameter of the theodolite would at each successive ⊙ be set parallel to the zero line A⊙1.

The chaining would be commenced at A.

SECTION XXI.

PLOTTING.

It is in the operation of plotting, that the chief advantage of the "back angle" system of traversing is found; all the angles having reference to one zero line, can be set off with a certainty and facility which could not be otherwise attained.

The direction of the traverse lines should, if possible, be laid down with the circular cardboard protractor, described in connection with the pocket sextant. A hole about $\frac{1}{10}$th of an inch diameter should be cut out at the centre, for the convenience of adjusting it to any point on paper.

It may be presumed that a large rolling ruler, or the marquois scale and triangle, is available for carrying a parallel line.

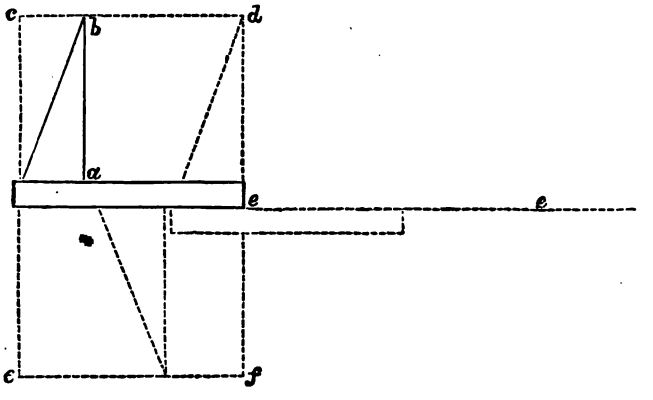
If a side of a triangle has been adopted as the zero line of the traverse, the 0—180 diameter of the protractor is adjusted to the corresponding line in the plan; the centre point is marked; a weight is laid on the protractor to keep it from moving; and the position of all the forward angles is marked on the plan with a fine-pointed pencil, or pricked off with a needle round the circumference of the protractor. The degree is written at each point, so that it may be identified.

The protractor is now removed.

The position of all the ⊙'s will be first laid down, so as to ascertain whether the plotting "closes" correctly, before proceeding to draw any of the detail.

The direction of each traverse line in succession is drawn from the preceding ⊙, by a line parallel to that connecting the centre of the protractor with the forward angle marked at the circumference. The marquois triangle can be used for carrying a parallel line to some distance, if its bevelled edge be adjusted to the given line *ab*, and a

FIG. 95.



scale laid against its base and firmly held down; thus a line parallel to *ab* could be drawn anywhere within *c*, *d*, *e*, *f*. If the two scales be placed alongside, a line *ee* may be prolonged by sliding them against each other.

In regular survey establishments, methods of plotting superior to these makeshift arrangements are employed. The most accurate method of plotting is that of ordinates and co-ordinates, known as Gale's traverse system. The position of each ⊙ with reference to the point of departure is found by "traverse tables," so that each being independently determined, an error is not carried on throughout the plotting. This system is unnecessarily accurate for military surveying.

After the plotting of the traverse lines closes satisfactorily, the drawing of the intermediate detail is commenced. For this, a "plotting scale," as previously described, will be useful, saving the trouble of drawing perpendiculars for the offsets, and of taking the measurements by compasses from the scale. The field book should be laid on the plan, with the direction of the chain column corresponding with that of the plotted traverse line, so that there may be no liability to mistake the sides to which the respective offset entries belong.

When the traverse is independent of triangulation, the zero line, whether it be the magnetic meridian or the first traverse line, will be drawn in any convenient part of the plan, and the protractor adjusted on it, as described.

A convenient and accurate way of plotting small scale surveys, is to use a large circular cardboard ring, or protractor with the inner portion cut out. The graduation of the circle commences from both ends of the diameter, and is carried in the same direction, so that each degree is repeated at opposite sides of the circle. The protractor is laid on the survey, with its diameter corresponding with the zero line; weights are then placed on it to keep it from moving.

To draw a given forward angle, adjust a parallel ruler to the angle marked at opposite sides of the circle; carry this line up to the given point, and draw a line from it representing the traverse line. When the space within the circle has been filled, the protractor is removed and readjusted to a fresh zero line drawn in a convenient position parallel to the first.

SECTION XXII.

THE CAVALRY SKETCHING CASE

Is intended to simplify the performance of rapid sketches on active service, a high degree of accuracy not being necessary. It contains all the apparatus required for the purpose, and can be carried in the pocket of a shooting coat, or in a sabretache; when sketching, it is strapped upon the bridle wrist.

The board is constructed to contain a strip of drawing paper, about 7 inches wide, and 2 or 3 feet long, being the most convenient shape for sketches of roads and rivers.

To fix the paper, cut a strip as long as required, and of width suitable to the board. Crease it perpendicularly to its length, at about $\frac{1}{3}$rd of an inch from each end. Remove the rollers by pressing back the springs which hold them. Each roller consists of two pieces, between which the paper is held. Place the crease of the paper in the groove of one piece, retain it there by the other, whilst the roller is replaced in the board.

Roll up the paper on one roller, so that the sketch may be commenced at the other end.

The compass box has a meridian line engraved on the glass, with which the needle must coincide, it's north end directed to the index or projection at one end of the line.

The compass box is capable of being turned round, in order that the meridian line may be placed in such a relation to the sketch that the road may occupy its centre. To do this, hold the board so that the length of the strip of paper may correspond with the *general direction* of the road. Now revolve the compass box by means of the projecting index, until the meridian line corresponds with the needle. If this be carefully done, the sketch will not run off the paper.

Draw a meridian line on the sketch parallel to that on the glass, and mark the north end corresponding with the index.

Care must be taken that the position of the compass box shall remain unaltered during the sketch, unless it becomes necessary to change the general direction, as presently described.

To draw the direction of the road, or of any object—

1st. Turn the horse exactly in the direction of the object.

2nd. Revolve the board on the wrist until the meridian line corresponds with the needle. The oscillation of the needle may be checked, if necessary, by tilting the board a little, but the latter must be level when the direction is being drawn.

3rd. By moving the arm to right or left, bring the point from which the line is to be drawn on the sketch, opposite the centre of the body. Now turn the ruler in the required direction, its edge corresponding with this point, and draw the line; but just before doing this, glance again at the meridian line, to see that it coincides with the needle, and that the latter does not touch the box. A slight alteration of the board is now better effected by moving the arm than by revolving the board on the wrist.

The alignment of the ruler towards the object is a matter of judgment and eye. After a little practice the whole operation as described may be accomplished in about 15 seconds, correct within 2°. A horse will generally stand still long enough to permit the direction to be drawn.

Should the road change its *general* direction, so that it would no longer follow the centre of the paper, a line should be drawn across it, and the sketch re-commenced here. The meridian on the compass box is altered (as on commencing the sketch) to suit the new direction, and is drawn on this portion of the sketch. The starting point is taken in the centre of the sheet, and 2 or 3 inches above the line. These alterations of meridian may have to be made several times, but the necessity should be avoided as much as possible by proper arrangement. When the sketch is brought home to be finished, it is cut across the line where the meridian was changed, the points where the sketch was discontinued and re-commenced are made to coincide by a pin driven through them into a board; the pieces turned so as to bring their meridians parallel, and firmly pinned in this position, whilst both are cut through at one cut with a sharp knife.

If this be properly done the cut edges will meet exactly, and may be united by a strip of paper pasted on the back.

The sketch when finished up, should be rectangular, with the road in the centre, and the names of places and other printing parallel to the top and bottom margin. The sketch, if necessary, may be mounted on another piece of drawing paper; in doing this, the whole of its back should not be pasted, but only the extreme edges, otherwise the expansion of the paper would prevent its drying flat. A weight should be laid on it whilst drying.

If the route be indicated on a map, the meridian line can be set in the required relation to the sketch with greater certainty. As the direction of the magnetic north on a map in England lies about 18° to the left of the side margins, a line in this direction may be drawn through the portion to be surveyed (or it may be estimated). The sketch sheet is held on the map so that its length shall correspond with the road, and whilst in that position, the compass-box is revolved so as to place the meridian on its glass in the same direction as the magnetic meridian on the map.

The board may be used on foot, for sketches where high accuracy is not required, such as rapid sketches of positions for outposts.

Horses soon learn that they are meant to stand steady for a few seconds whilst the direction is being observed, but being generally fidgetty in company, they will do the work best when alone.

The scales of horse paces may be drawn on the edge of the ruler. These scales should not be numbered, so that it may not be necessary to adjust their zero to a point on paper.

Besides scales of horse's paces, a scale of hundreds of yards must be drawn on the ruler, by which objects on each side of the road may be placed at their estimated distances.

SECTION XXIII.

ORGANIZATION OF COMBINED SURVEYS.

The "modus operandi" will be considered first on the supposition that the country is unknown; that there is ample time; and that instruments are available, suitable for accurate work.

Secondly, that the ordinary small-scale Government maps are available, upon which to base the military large-scale survey of the country.

Thirdly, that an army is operating in an unknown country; that only the ordinary sketching instruments are available; and that merely a rapidly executed sketch of the country adjoining the line of march is required.

When a number of persons are employed in surveying a district which has not been previously mapped, the only way in which accurate results can be obtained is by first determining by triangulation the position of a number of conspicuous and easily recognised points throughout the country. This triangulation carefully laid down on one large sheet is the basis of the survey, and by its means the general accuracy is secured, independent of the minor errors that may pervade the component surveys executed with instruments of inferior accuracy.

The country is next divided into equal portions according to the number of surveyors, the portions being bounded, if possible, by natural definite limits, such as roads, rivers, or watersheds.

The trigonometrical points contained in each portion, are transferred or "pricked off" to the several survey sheets, and the calculated distances between the points are given to the surveyors.

Each portion may have but one or two points given in an extent of 8 or 10 square miles; from these the position of interior points will be determined by secondary triangles with as much accuracy as can be obtained by the instruments provided. Trigonometrical stations beyond the actual limits of his portion may be also given to each surveyor, by means or which he may either determine interior points by "adjustment," or by triangulation.

The methods of "filling in" the details of the ground with various instruments have been explained, and need not be recapitulated.

When finishing up the portions, a margin of about half an inch round each, should be left in pencil; for as the work of even the best surveyors will under the circumstances be only approximately correct, there will be some non-agreement in the meeting of roads, fences, &c., in their mutual borders, requiring a certain amount of alteration in these portions. These alterations will be made in pencil whilst both surveys are adjusted side by side on the general triangulation, by means of the given trigonometrical points.

The Officer charged with the organisation of the operation distributes the work and combines the surveys. If a number of Officers are employed, he should divide the country into groups (each of three

or four surveys) in charge of Officers who will be furnished with tracings of the original triangulation of their groups.

When the surveys of a group are finished, with the exception of the marginal portions left in pencil, the Officer in charge of the group will adjust them together by means of the given trigonometrical points; and fasten them down firmly on a deal table by pins every two or three inches close along their mutual boundaries. He will then cut firmly through the paper with a sharp knife, held vertically, taking care that the cut has not to be repeated, and that the overlying surveys do not move in the slightest degree upon the lower. The cuts will be made close along the boundaries, so as to leave the road, river, or whatever it may be, in one survey only. He will leave a margin of an inch or two uncut all round the *outer* edge of the group, and this portion will be left in pencil until his group has been adjusted with others on the general triangulation and their margins cut through, in the same manner, by the Officer in charge of the operation.

If this cutting be skilfully done, the junction of the surveys will be barely perceptible. They should be laid on their faces, accurately joined, and connected temporarily by small pieces of adhesive paper every two or three inches; then turned over, and the necessary alterations made in the marginal portions. They are then separated, and the margins finished up; after which they are rejoined at the back more firmly than before, and the group is ready to take its place in the combined survey.

Should there be any wide non-coincidence of detail in the margins of adjoining surveys, the error should be traced and corrected on the ground if there be time.

Each surveyor should sketch the hills in contours at the same vertical interval. But in a combined survey it would be unnecessary that the contours by which the hills are represented, should be at *common levels* throughout all the component surveys; this would be very difficult to arrange, and would add nothing to its value for military purposes. All that is necessary is, that the shape and slopes of the hill features should be correctly represented in each portion, so that though the roads and all existing detail should meet accurately in the mutual margins, imaginary lines such as contours need not so meet; the temptation to make them do so when correcting the marginal portions should be avoided, as tending to the misrepresentation of ground. Each surveyor will commence his contouring at any level that may suit him.

In Plate X it will be perceived that though the contours of adjoining portions do not meet, the representation of the general shape of the features is not affected thereby.

The present system of lead shading is peculiarly suited for producing uniformity in a combined survey. After all the surveys have been joined, a little blending of the margins only is required. The whole may be then indelibly fixed by a spray of weak gum-water blown over it.*

To ensure uniformity, each surveyor will be instructed as to the size and type of printing to be used, whether roads are to be coloured, and woods shown by pen, or by a flat wash of green.

Printing will be, as a rule, on lines ruled east and west; but should the meridians be oblique to the shape of the paper, as will be some-

* The "fixateur rouget" sold by Lechertier and Co. answers the purpose well, and there is no danger of its causing water colour, printing, &c., in the survey to "run."

times necessary, each surveyor should have a line given on his portion for the direction of printing parallel to the top of the general survey.

Should the prismatic compass be used for the "filling in," each surveyor will commence by carefully taking the bearing of one of his given trigonometrical points from another, so as to be able to lay down a magnetic meridian on his portion, in its proper relation to these points. The other magnetic meridians will be drawn parallel to this.

With the plane table he will commence by "setting" the survey at one of the trigonometrical points, by the ruler adjusted on the line connecting this point with another; then lay the compass box on the table so that the needle may point to the index, and draw a line along its edge, which will be the working meridian, by means of which the table will be "set" every time the needle is used for the purpose.

Considerable time would be required for the execution of a survey thus based on trigonometrical stations. The arrangement, observation, computation, and construction of the triangulation alone would occupy more time than the survey of the detail.

Secondly. When there is neither time nor means to triangulate the country, the government maps may be used for arranging and distributing the districts and for subsequently combining the surveys. The object of resurveying the ground being to show its tactical capabilities and recent alterations.

The Officer in charge of the operation will cut out from the map the groups into which the country is to be divided, and hand these over to the Officers in charge of groups, who will further subdivide them into districts bounded as much as possible by roads; and will combine the surveys of these districts when completed.

Each surveyor will fasten his portion of the map on his sketching board, and will study the general map so as to recognise the limits of his district, and impress on his memory the relation of his portion to the whole; the position and direction of rivers, watersheds, &c.

He should also draw on his portion of the map a magnetic meridian, whereby he may recognise its relation to his work done with the compass.

The chief difficulty in combining these surveys is, that an error cannot be at once noticed and traced to the portion in which it exists (as would be the case when each survey contains one or two trigonometrical points).

Only good military surveyors should be employed in a combined survey, but even their work will, in the absence of a general triangulation, be merely an approximation. Even if there be time for each to measure a base and perform a triangulation of his portion, there will be room for much inaccuracy in the traversing, so that the roads, rivers, and fences will not meet exactly in the margins of adjoining portions.

If there be no opportunity of executing separate triangulations, and if the surveyors have to trust entirely to the accuracy of their traversing, the errors will be larger, and the task of combining the sketches will require much judgment.

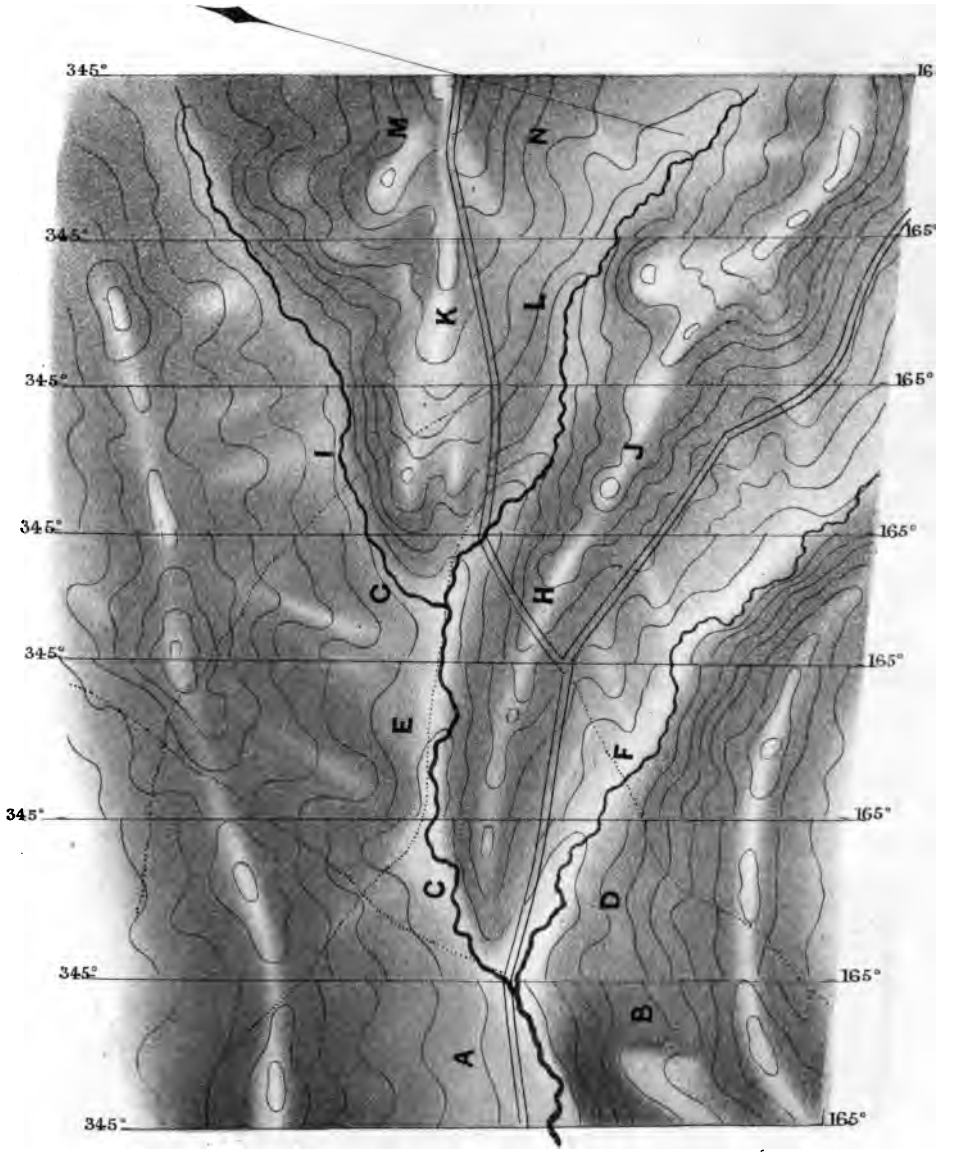
The chief guide will be the true meridians, which each surveyor will lay down on his portion with care, having ascertained the exact variation of the compass with which the survey was executed. This true meridian, being the one thing common to all the surveys, the lines representing it will be parallel in each.

Thirdly. When a general triangulation is impracticable, and there is no map of the country, the track on which the army marches will form the common boundary between the sketches made on either side of it. A certain "bearing" should be adopted as the lateral boundary of each sketch (345° in Plate X); this bearing should be nearly perpendicular to the general direction of the track, and should be noted by each surveyor. On being shown the limits of his portion of the track, he will find by trial an object in the distance belonging to this bearing as shown by his compass, and will traverse the line in this direction carefully, as far as the depth to which his sketch is to be carried from the track.

Each surveyor should be made especially responsible for the accuracy of one of his lateral boundaries; and each pair of surveyors, as A and B, C and D (Plate X), for the correctness of the portion of the track which is common to them. Suppose that each surveyor be made responsible for the correctness of the eastern boundary of his work (Plate X), he will devote his attention to this line, and trust to the man on his left to traverse the western boundary accurately. In this way a much greater general accuracy may be obtained than if each man were to employ his time in sketching every part of his ground with equal care. In combining the sketches the necessary alterations will be made in the western margins only.

The officer in charge of the operation will walk along the track with the surveyors, and leave a pair at each point of division of the surveys; these points should be well marked by natural or artificial objects. The width of the sketches should be nearly the same. The combination of sketches performed thus, is very simple.

PLATE X.



SECTION XXIV.

ROADS.

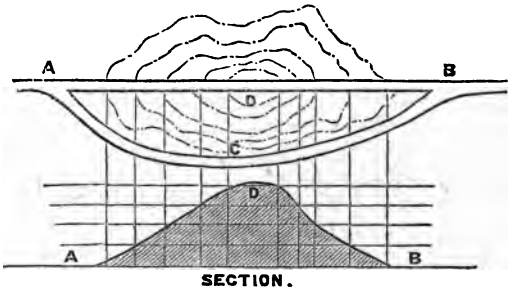
The conditions desirable in a road connecting two places are that it should be straight and level. Both these conditions cannot be fulfilled by a road in ordinary country; if level, it must follow a winding course, avoiding the eminences; if straight, it must ascend and descend them. As a rule, "straightness should be sacrificed to levelness," and it is to be noticed that a road which winds through an undulating country is not necessarily longer than if it had been constructed straight over hill and vale in the manner of the old Roman roads: for these are straight only in the vertical plane, but curved in the horizontal plane; so that it might be possible that the increased length of a road, incurred in avoiding the slopes, might not be much greater than that incurred in ascending and descending; the advantage in such a case being all in favour of the former.

For instance, the level road ACB (Fig. 96) is no longer than the straight road over the hill ADB.

A general rule is, that in order to avoid an ascent, it is allowable to increase the length of the road twenty times the vertical height avoided.

When the ascent of a hill is unavoidable, the road should, if possible, be laid out so as to ascend continuously and never to descend partially. By ascending the hill obliquely, the gradient of the road

FIG. 96.

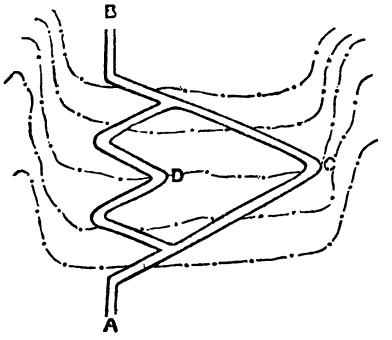


SECTION.

may be made as slight as may be desired, but its deflection from the straight line is the greater as the slope is slighter; so that in laying out a road, the relative advantages of levelness and shortness have to be balanced. Sound judgment is required to decide the increased length which would be equivalent to a given slope; or conversely, the steepness which it would be justifiable to give to a road in order to avoid a wide deviation from the required line of direction.

It may be necessary to zigzag the course of a road in ascending a slope at a given gradient. As regards total deviation from the line of direction AB, the increased length of the road ACB (Fig. 97) is no

FIG. 97.



greater than that of ADB, but the former is preferable, on account of the loss of tractive power at the turns and the greater labour and expense of constructing the latter.

In laying out a road for ordinary purposes, the value of land enters into the question, and often limits the deflection from the line of direction. But in military roads, such as that constructed in 1855 to connect the camp before Sevastopol with the base of supply at Balaklava, such considerations do not exist.

THE GRADIENT.

The effect of different slopes upon the tractive force applied to vehicles must be understood. To move a load up hill it is necessary to lift vertically the same proportion of the load as the height of the hill is to its horizontal length; thus in drawing a load of 2,000 lbs. up a slope of 1 in 20, the horse has continuously to lift $\frac{1}{20}$th of 2,000 lbs., or 100 lbs., besides the power necessary to draw the load on level ground.

Experiments show that on the moderate gradient of 1 in 24, or about $2\frac{1}{2}°$, a horse can only draw one half as great a load as on the level; on a slope of 1 in 10 only one quarter as much.

The "angle of repose," or slope on which friction balances the inclination of a two-wheeled vehicle to roll down hill on a good road, is found to be about 1 in 35. Some horses can for a short distance exert six times their ordinary force, and might drag a light load for a very short distance up a slope of 1 in 10, but in constructing military roads such a gradient should not be approached.

A strong horse dragging a load of a ton will rarely face a gradient of 1 in 20, but will almost invariably "tack" up it, thereby reducing the steepness by increasing the distance. And though hills as steep as 1 in 8 may occasionally be met with in country roads, horses do not really drag heavy loads straight up them, but by zigzagging reduce the gradient to that which it lies within their power to accomplish.

For military roads the maximum gradient should rarely exceed 1 in 20. Such a gradient will retard the ordinary speed of a loaded wagon by one-half on a good road, and if the hill be more than 100 yards in length, horses will require to stop for breath.*

* Some of the most experienced civil engineers consider 1 in 30 to be the maximum gradient at which a road should be constructed.

The Roadway.

Roads for military purposes need only be wide enough to permit wagons to pass each other; for this 16 feet will be sufficient. Ordinary roads vary from this to 30 feet, according to their importance. This is, of course, irrespective of the width between the fences which bound the road.

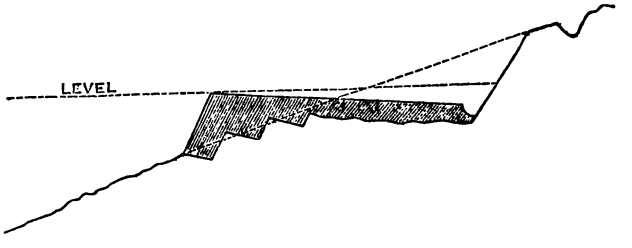
The centre of roads is made somewhat higher than the sides, so that rain water may at once run off into the ditches on either side. A slope of 1 in 24 is usually given from the centre.

Fig. 98.

A segmental section would make the centre too flat and the sides too steep, thereby inducing vehicles to keep to the middle of the road, and causing the wear to be unequal. The section should therefore consist of two inclined planes, with the angle at the centre slightly flattened.

On a steep hill side, the cross section of the road is usually a plane inclined towards the hill (Fig. 99), and with the ditch on the inside, connected with numerous "culverts" (or drains passing under the road), to discharge the water. This system is adopted to save the

Fig. 99.



road from the injurious effect of water running over it from the high ground.

When a road zigzags up a hill, it should be level at the turns, and its width should be increased at these points about one-half, otherwise the leaders of a team would be unable to assist, and the work would fall altogether on the wheelers.

The dryness of the bed of the road is of the greatest importance; not only must no rain-water be allowed to rest on the surface, but all water should be drained from the earth beneath the road, else the latter will be continually out of repair. Therefore ditches must be dug one or two feet below the level of the road-bed, their depth and width will depend on the nature of the soil and the amount of water to be discharged, also on the fall of the ground and the rapidity with which water will flow: in wet, peaty, or friable soil the ditches must be at least 3 feet clear of the road, as their sides crumble away and fall in, particularly in frosty weather.

The stone work of a road consists of two portions, the bed and the surface; the former should be composed of large blocks of stone, brick-bats, &c., the interstices in which facilitate drainage; the latter of finer material giving as smooth a surface as possible, the latter should be renewed as it wears out, so that the traffic of the road may never come on the bed.

The best stone for the surface of roads is that which combines hardness and toughness, such as basaltic or trap rock. Carboniferous mountain limestone binds and wears well. Flints, though excessively hard, are too brittle, and pulverise quickly. Granites are bad, except those which contain horneblende in place of felspar, known by their dark colour. Certain kinds of gravel are good road material.

The surface stone or "metal" should be broken into pieces about $2\frac{1}{2}$ inches diameter; a layer of about 5 inches of this should first be laid. When this has been crushed down by traffic or by heavy rollers, and is nearly consolidated, another coating of about 3 inches should be added. Whilst the road is being formed, the traffic should be made to pass over every part of its surface equally, and the stones should be kept raked into the ruts worn by vehicles. After a little wear, a third coating of about the same thickness may be required.

The surface of the road is nothing but a hard inelastic shell, to keep the road bed dry and to distribute the weight of passing vehicles equally over it. The compactness and solidity of the metal of a good road can be best realised by noticing the difficulty with which it is broken up or "lifted."

Large stones should not be allowed to mix with the metal, as they will not bind, but will have a tendency to turn over and keep the surrounding stones loose.

Gravel from pits forms a good road. The lower coats should be of "screened" gravel about $2\frac{1}{2}$ inches diameter; on the surface may be laid a coating of "binding" gravel containing a certain amount of grit, but no earth.

When a fresh coating of metal is to be laid on a firm road, the surface of the latter should be scored transversely with the pickaxe, so that the new metal may amalgamate with the old. River or sea-beach gravel is too rounded and clean, and will not bind unless broken, or until crushed by traffic.

If the road bed be rock, the projecting points should be cut off and covered with a layer of earth before the road metal is laid down.

In marshy ground the road bed should be raised above the general level, by sods laid on it. Brushwood or heath forms an excellent substratum to a road, permitting the water to percolate, and keeping the road dry.

Laying out the line of the road.

If contour plans of the country are available they should be carefully studied, and that which is apparently the best line selected, before entering into a particular inspection of the ground itself. Some idea of the probable site of the road may be gathered from any existing maps, however rough.

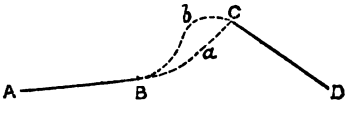
Supposing that the site of the road is to be selected solely with regard to the physical formation of the country, and that the necessity does not exist of diverging for the sake of passing through certain villages in the vicinity, there will usually be some feature, such as a ridge, more difficult to cross than the rest. If there be a part of

this feature at which it can evidently be passed more easily than elsewhere, this constitutes a "ruling point" in the line of road. In a chain of hills the lowest "col" would be the ruling point, supposing that it is not too far out of the direct line, and that there is no great impediment to the construction of the road in the approaches to the col on either side. If a river is to be passed, the road might diverge from the straight line to a ruling point, where the channel is narrow and the banks particularly favourable for the construction of a bridge.

The primary ruling points having been determined, those connected with features of secondary importance are examined, and the comparative merits of alternative lines considered, deviating as little as possible from the direct line.

A maximum limit of gradient may have been specified in the instructions. If the road has to pass over a hill steeper than this gradient, it is not always necessary to lay it out at the greatest allowable slope throughout, but at the average gradient between ruling points which may have been selected upon it. It is only by trial that the best line between two ruling points can be fixed; it may be necessary to modify the first idea, and the alteration of one part will entail a distribution of the change throughout the adjoining portions. Thus, supposing AB (Fig. 100) to be the direction of the road to lead into another portion, CD, the first idea may have been to lay out the road as shown at *a*, and it would only be by repeated alteration that the better line, *b*, could be arranged, avoiding the sharp turn at *c*. Such a turn is objectionable, not merely as being unpleasing in ap-

FIG. 100.



pearance, but also as causing loss of power applied to check the speed of a vehicle and start it in a new direction.*

The first operation in laying out the road on the ground is to place pickets, marking its centre, at short intervals throughout its length. The Watkin clinometer is useful in this operation to observe that the maximum limit of slope is not exceeded; thus, supposing the limit to be 1 in 30, the surveyor, looking through the instrument, can signal to an assistant to move up or down hill at a convenient distance, usually from 20 to 50 yards, until the place is found where the top of a pole, the same height as the observer's eye, coincides visually with 2° in the clinometer (2° being practically equivalent to 1 in 30). The assistant plants a picket here, to which the surveyor advances and repeats the operation. For the purpose of laying out the road, it will be divided into portions, each lying between two "ruling points," between which the gradient will be made as uniform as possible. Should the line on approaching the finishing "point" be found to have reached too high or too low a level, the pickets will be shifted so as to equalise the gradient throughout.

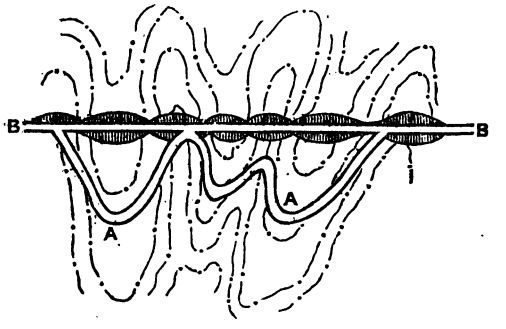
* In the construction of railways, the setting out of simple and of compound curves of large radius is performed by rule with an exactness which would be unnecessary in roads such as those here described.

A level and straight road might be constructed between two places in undulating country, by cutting through the hills and making embankments over the hollows with the excavated earth; but this is a method involving so much labour and expense as only to be justifiable in extreme cases, and when it is evident that the labour is little greater than would be required to construct a longer road avoiding the undulations.

A certain amount of cutting may be advantageous when serving the double purpose of reducing the gradient and of supplying gravel or stone, which would have to be quarried somewhere for the construction of the road.

The choice may be between the construction of a very tortuous road with moderate inclines, such as A, following the contour round the features, and a straight road, B, levelled by alternate cuttings and fillings.

FIG. 101.



If the elevations and depressions are slight, the latter road would be the best; but if the depressions are deep the labour of constructing A might be found by calculation to be much less than B.

The amounts of cutting and filling should balance each other; the calculation of cubic contents of each being made as for parapets and ditches, and allowance made for "foisonnement" or increase of bulk.

The slopes of the side of cuttings and embankments will depend on the nature of the soil; in good chalk a cutting can be nearly vertical; in loamy sand, $\frac{1}{2}$; in ordinary clay, $\frac{1}{1}$; marly clay will not stand at a steeper incline than $\frac{1}{4}$.

In considering whether the watersheds, the valleys, or the sides of hill features are best suited for the sites of roads, preference should be given to the first, because in that part there will be the smallest amount of water, and the drainage of the road will be most easily provided for; also because the cross-lifting of earth which makes road-making on a hill side laborious, is avoided.

The centre of the road having been marked out by pickets, the level at which the road bed is to be constructed must be plainly shown; this is done by "boning staves" and pickets. The former are merely pieces of wood of similar length (about 4 feet), with a cross-piece nailed on them, used thus:—Suppose the ground between A and B is to be brought to a uniform slope, pickets are driven in at these points with their heads a similar height above ground. Boning staves being held on these as shown, a person at A looking along the line formed by the tops of the boning staves, can direct a third person as to the

FIG. 102.

depth to which he will hammer pickets in the intervening ground until the head of a boning staff, held on each picket in succession, comes into the plane of sight. It is then only necessary to direct the working party to cut or fill the ground to within a similar number of inches from the top of all the pickets.

The width of the road is measured on either side of the centre pickets; after which the exact edges are marked by a continuous narrow cut, called a "lock spit," made in the turf. The pickets which mark the width of the road should be hammered in so far that their heads may show the level of the sides of the bed, with a fall of 1 in 24 from the centre, as previously mentioned.

The ditches will also be marked out, and the side paths when required.

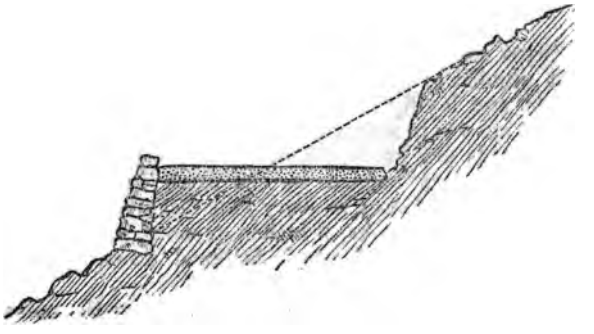
An accurate survey of the proposed road should be prepared on a scale large enough to show the minutest detail, usually $\frac{1}{2000}$ or $\frac{1}{1000}$. Also sections where any peculiarity of construction occurs, such as where the road is partly cut out of a hill side, and designs of the bridges that are to be erected.

MOUNTAIN ROADS.

In the Himalayas especially, soldiers are much employed in road making, and therefore some of the peculiarities of these roads may be noticed.

The Himalayan watersheds are usually so steeply inclined, that the sites of road cannot be found on them; the roads are, as a rule, "nicked," or cut out of the hill side, the excavated earth being thrown down the mountain. Occasionally the slope of the hill side is gentle enough to afford some foundation for the excavated earth; when this is the case, the labour of construction is much reduced. A retaining wall is built, as shown in the figure, usually of dry stone, to support the earth. In the roads near hill stations, this wall is raised about 3 feet, forming a parapet wall to prevent accidents; openings for the escape of rain-water are left here and there in it. A drain is

FIG. 103.



formed on the inner side of the road to catch the surface-water; this drain passes through culverts under the road at intervals depending on the quantity of water, and discharges it down the mountain.

Sometimes the water is carried across the surface of the road in "water tables" or shallow paved depressions, constructed obliquely to its direction, so that both wheels of a vehicle may not strike the depression simultaneously.

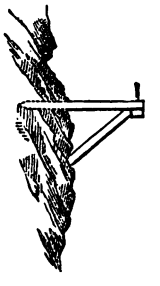
The chief difficulty and expense in these roads is in providing water-way at the places where they cross gullies. During storms, a body of water rushes down these with force enough to sweep away any obstruction, so that capacious bridges have to be constructed over insignificant watercourses. Great damage is done by landslips, caused by cutting the road out of the hill side, and thereby depriving the latter of its foundation. The earth or shale has always a tendency to resume its natural slope, and when weighted after heavy rain, the increased gravity overcomes the friction, and the mass descends, sweeping away the road or covering it. These accidents cannot be provided against in a new road.

It is only a very few important routes that are constructed for vehicles. The roads are usually made only wide enough for pack mules and bullocks (8 or 10 feet). The soil is such as to answer as a roadway without any further preparation than levelling.

In some places (*e.g.*, the Thibet route) the road is bracketed on to the face of cliffs which are not compact enough to bear undercutting.

The road is carried on a framework, of which the transverse pieces are wedged into holes drilled deep into the rock, and the outer edge supported, as shown (Fig. 104), by an oblique prop every 8 or 10 feet.

FIG. 104.



WOODEN ROADS.

In forest country, "corduroy roads" are formed by "felling a sufficient number of young trees, as straight and as uniform in size as possible, and laying them side by side across the road." Such a road would answer in swampy ground.

Plank roads are used in America. Longitudinal sleepers, about 6 inches thick, are bedded in the earth with their upper surface flush with it; one sleeper to every four feet width of road. On these are laid transverse planks, 3 inches or more in thickness and about 1 foot wide; every tenth plank fastened down to the sleepers by spikes.

A piece of planking should be placed under the point of junction

of longitudinal sleepers to support this weak place where the weight is not distributed over a wide surface.

The roadway depends chiefly on the earth for its support, and care is taken that there is no space between the planks and the earth. The sleepers are mainly of use in keeping the planks in position.

The roadway is usually 8 feet in width, sufficient for one wagon. Alongside the roadway is an earthen track, usually 12 feet wide.

Ditches to keep water from the road-bed are dug on each side.

A layer of fine gravel or sand is thrown on the surface; this becomes incorporated in the grain of the wood, and presents a perfectly even surface.

A road of this description might be improvised of railway sleepers.

The friction on plank roads is calculated to be one-third of that on macadamised roods.

Swampy ground may be made firm enough for the passage of artillery by merely coating it with hurdles, fascines, or branches laid across and across each other, the top layer being transverse to the road. The flooring planks taken from houses near the place form a good substratum to a surface of brushwood and branches.

SECTION XXV.

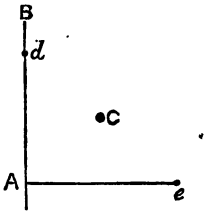
DETERMINATION OF HEIGHTS AND DISTANCES.

Problem I.

To trace a right angle, or a perpendicular to a given line.

A method suitable to any situation and practicable without the aid of a second person is: Let A (Fig. 105) be the point at which a perpendicular to the line AB is required. Plant a peg at any convenient point C, about 10 or 12 feet from A. Place the noose of a cord over C,

Fig. 105.



take the length AC, and at this distance place one peg at d, in the given line, and another at e in the line dC produced. e belongs to the perpendicular. By means of this problem, the following can be performed.

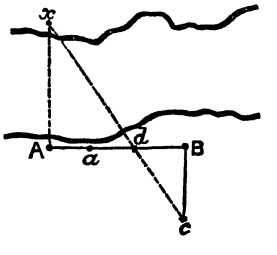
Problem II.

To find the breadth of a river or the distance of an inaccessible point

By Geometry.

The distance of x from A being required. Place a mark at A and another at a, perpendicular to Ax.

Fig. 106.



In the prolongation of the line marked by A and a, place a picket B, and another at a convenient point c, perpendicular to BA. Stand-

ing at c direct an assistant in placing picket d in the line cx, he at the same time placing it in the alignment Aa.

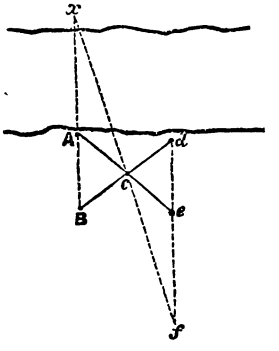
The triangles xAd, dBc, are similar. Measure cB, Bd, dA.

Then $dB : Bc :: dA : Ax$.

Observe that in constructing these figures on the ground, their size must be proportioned to the distance of the object.

Second Method.—Place a mark at B in prolongation of xA, another

FIG. 107.

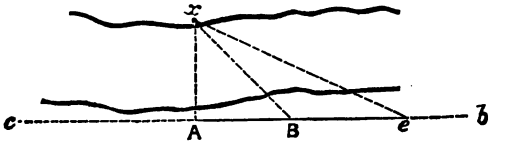


at a convenient point c. Make cd equal to cB, and ce equal to Ac, and place d and e in the prolongations of Be and Ac respectively. Find f where xc and dc would intersect when produced. The triangles xAc, fec are similar and equal; and ef, equal to Ax, may be measured.

With the Pocket Sextant.

Set the index at 90°, and find some distant object b, perpendicular to Ax.

FIG. 108.



Set the index at 45°, and move along this line towards b, until A and x coincide by reflection. AB is equal Ax.

It is important that the observer should be exactly on the perpendicular when finding B. In many cases it may be better to look for a point c belonging to the perpendicular in the opposite direction; then the observer can align himself on Ac when moving outwards towards B.

The observer should stand with the sextant vertically over the picket.

By reference to the accompanying table of natural tangents, the proportion between the sides may be readily found at various convenient angles besides 45°.

Multiplier.	Angle.	Divisor.	Angle.
1.....	45°	1.....	45°
2.....	63 26′	2.....	26 34′
3.....	71 34	3.....	18 26
4.....	75 58	4.....	14 2
5.....	78 41	5.....	11 19
6.....	80 32	6.....	9 28
8.....	82 52	8.....	7 8
10.....	84 17	10.....	5 43
12.....	85 14	12.....	4 46
15.....	86 11	15.....	3 49
18.....	86 49	18.....	3 11
20.....	87 8	20.....	2 52
25.....	87 42	25.....	2 18
30.....	88 6	30.....	1 54

Set the index at any of these angles, and move along the perpendicular AB until A and x coincide by reflection. If the angle be greater than 45°, multiply the distance by the figure opposite the angle; if less than 45°, divide. The quotient or product will be the required distance.

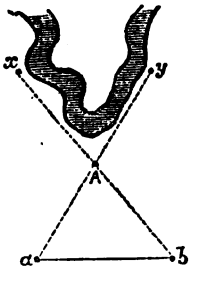
Thus, if at e (Fig. 108) the angle xeA be 26° 34′, and the length of Ae be 150 yards, the distance Ax will be $\frac{150}{2} = 75$ yards.

Problem III.

To find the length of a line accessible only at the extremities as xy.

Place a mark at a convenient point A; another at a in the prolongation of and equal to Ay; and a third at b in the prolongation of and equal to Ax.

Fig. 109.



aAb is equal and similar to xAy, and the distance ab may be measured.

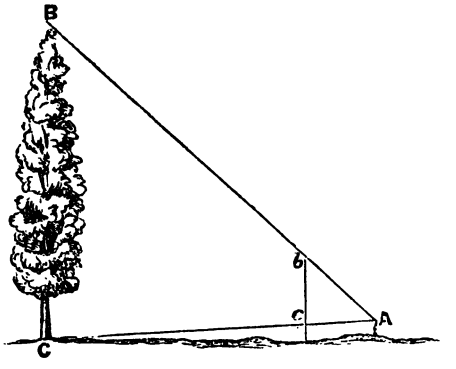
Problem IV.

To find the height of an object accessible at the base on level ground.

By Geometry.

At any convenient spot plant a pole vertically and a picket in line with the object.

FIG. 110.



At A, observe and mark the points *bc*, in which the lines AB, AC intersect the pole. Then the triangles A*bc*, ABC being similar, measure A*c*, *cb*, AC—

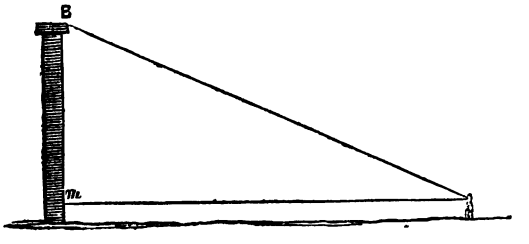
A*c* : *bc* :: AC : BC.

With Pocket Sextant.

Make a mark *m* on the wall at the height of the eye. Set the index at one of the angles given in the tangent table. Find a place where *m* and B coincide by reflection in the sextant. Measure the distance from this place to the foot of the wall under *m*; multiply or divide this distance by the figure given for the angle. To this add the height of the eye above the ground. The angle 45° will give the distance equal to the height.

In observing near objects, the parallax of the sextant might be appreciable at some angles, but would probably produce no error greater than one inch in the height of the object.

FIG. 111.



With the Clinometer.

It is unnecessary to mark the height of the eye on the wall, as the instrument records the vertical angle with regard to the horizontal plane. Find a place where the top of the object appears to correspond with one of the angles given in the tangent table (as before) and divide the distance to the object by the figure corresponding to the angle. The quotient, plus the height of the observer's eye, is the height required.

The clinometer being divided to show degrees only, the quantity equal to the number of minutes must be taken by estimation.

If the sun be shining plant a pole vertically; measure its height and the lengths of its shadow, and that of the object.

The shadow of the pole will evidently be to its height in the same proportion as the shadow of the object to its height.

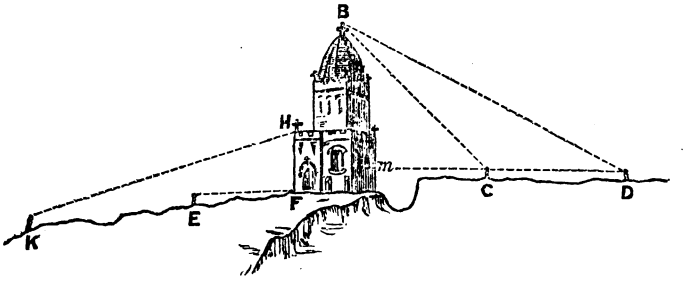
Problem V.

To find the height of an object, inaccessible at the base, on level ground.

With Pocket Sextant.

Find a place, D (Fig. 112), where the top of the object B and a point *m* (estimated as the same height as the observer's eye) coincide

Fig. 112.



by reflection; the index having been set to any convenient angle given in the tangent table. Make a mark on the ground at this place.

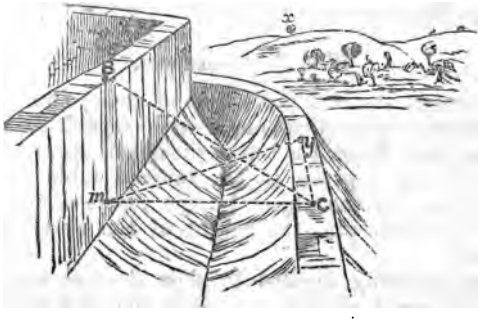
Set the index at a larger angle (as 45°), and advance in a direct line towards the object until C is found where B*m* subtends this angle.

Measure the distance CD; divide it by the difference between the numbers opposite the angles in the tangent table. The quotient is the height to which must be added the height of the observer's eye.

Thus, if B*m* subtend 14° 2′ at D, and 26° 34′ at C, and the distance CD be 90 feet, the difference between the divisors is 2; the top of the building B is therefore 45 feet above the observer's eye.

Or, if the space be limited, observe the angle *m*CB (Fig. 113), *m* being vertically under B. Find a point *x* in a horizontal line perpendicular to *m*C. Set the index at the complement of the angle *m*CB, and move along this line until *y* is found, where *m*C subtends this angle. Measure *y*C, equal to B*m*. Add the height of the eye.

Fig. 113.



Thus, if the angle mCB be 21° 10′ the index is set at 68° 50′ to find y.

This method has the advantage of being independent of tables of tangents and all calculation; it can be employed on level ground whether the base of the object be accessible or inaccessible.

Clinometer.

With the clinometer the tangent tables may be employed as above explained (Fig. 112), the observer advancing towards or retiring from the object, until its top appears to coincide with the required degree.

By Geometry.

Similarly to the method shown in Fig. 110, but the object being inaccessible, the distance AC must be found by Problem II. The triangle Abc will usually be so much smaller than the similar triangle ABC, that the slightest error in the verticality of the pole or in the measurements of Ac, cb, will produce a large error in CB.

PROBLEM VI.

To find the height of an object accessible at the base on sloping ground.

By Geometry.

Similarly to the method shown (Fig. 110).

By Clinometer.

Find the points at which the vertical angles of the top and of the foot of the object correspond with any of those given in the tangent table. Measure the horizontal distances of these points from the object. Calculate the height of each, and thence the total height of the object.

For instance, at E (Fig. 112), the vertical angle of the foot of the object is obtained, 2° 52′ (divisor 20).

At K the vertical angle of H is 14° 2′ (divisor 4). The distance FE is 50 feet, therefore F is above the observer's eye $\frac{50}{20} = 2{\cdot}5$ feet.

The distance FK is 130 feet, hence elevation of H $\frac{130}{4} = 32{\cdot}5$ feet.

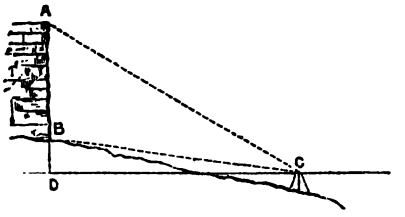
Height HF $32{\cdot}5 - 2{\cdot}5 = 30$ feet.

The heights of objects observed with the clinometer may be approximately found by constructing the figure on paper, and measuring the required dimension at the same scale as the horizontal distance.

By Trigonometry.

At any convenient point C observe with the theodolite the vertical angles ACD, BCD. Measure BC.

FIG. 114.



In the right angled triangle BCD, the angles and hypothenuse are known to find BD.

In the oblique angled triangle ABC, the side BC and the angles are given to find AB the height required.

PROBLEM VII.

To find the distance between two inaccessible objects and the difference of level between them.

Let C and D (Fig. 115) be the two objects.

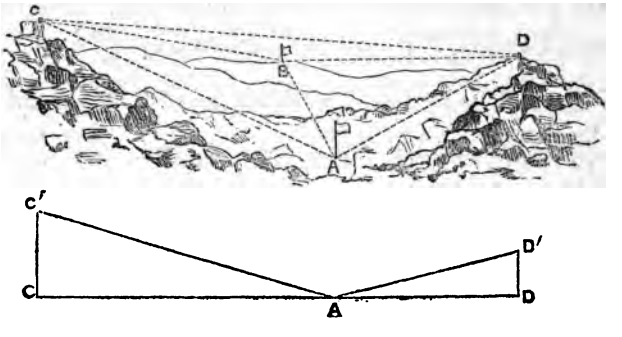
Measure a base, AB, of convenient length midway between them. Observe with the theodolite at A the angles BAC, BAD, also the vertical angles of C and D. At B, observe the angles ABC, ABD.

To find the sides AC AD, we have in the triangles ABC, ABD, two known angles and the side AB.

To find CD (or the distance between the inaccessible points) there are now two known sides AC, AD, and the included angle CAD.

To find the heights. In the right angled triangles ACC′, ADD′ the sides AC, AD and the vertical angles are given, to find the perpendiculars CC′ and DD′. The difference between them is the command required.

FIG. 115.



SECTION XXVI.

THE DETERMINATION OF THE LATITUDE AND LONGITUDE OF A STATION ON LAND.

It is assumed that the student is provided with a sextant of the usual construction, an artificial horizon, and, for the determination of longitude, with a chronometer showing Greenwich mean time; with a set of mathematical tables, such as that published in "Chambers's Educational Course,*" and with a Nautical Almanac for the current year. The explanations at the end of the Nautical Almanac are amply sufficient to direct the student in taking out quantities, and will repay very careful study.

The methods of finding the latitude and longitude of a station are, properly speaking, a branch of a larger subject, viz., Spherical Astronomy, and they cannot be fully treated without reference to that subject. Without going to any great length, however, it is possible to choose out so much of Spherical Astronomy as is necessary for putting the methods of finding latitude and longitude practically before the student. This is most conveniently done by means of definitions and a few remarks in explanation of them. The needful introduction can be considerably shortened when, as in the present case, the methods to be explained depend on observations of the sun and fixed stars only, to the exclusion of the moon and planets.

First Notions of Spherical Astronomy.

Introductory.—The appearance presented to the spectator by the heavens is that of the inside of a sphere of indefinitely great radius, on which the heavenly bodies are placed, and which turns with a uniform velocity about a fixed axis, one complete revolution being made in a (sidereal) day. This sphere is called the *Great Sphere*, and its daily revolution, in which all the heavenly bodies partake, is called the *Diurnal Motion* of the heavens. The direction of the diurnal motion is shown by the daily motion of the sun, who rises towards the east and sets towards the west. The ends of the axis of revolution of the great sphere are the *North and South Poles* of the heavens; these poles are vertically over the north and south poles of the earth respectively; the north pole is near the well-known star called the pole star.

When the heavenly bodies are observed, it is found that (with a few exceptions) they remain fixed relatively to each other, and, putting on one side minute motions which can only be detected by long-continued and very accurate observation, they have no apparent motion except the diurnal motion. These bodies are, therefore, called fixed stars. According to their brightness, the fixed stars are classed

* In the following examples, the "Nautical Almanac" for 1881 has been used, and the new edition of "Chambers," first published in 1878.

as stars of the first magnitude, of the second magnitude, of the third magnitude, &c., the brightest being of the first magnitude. They are also divided into groups called constellations; the principal stars within each constellation are known as α, β, γ, ... of that constellation; thus, the two stars of the Great Bear (called the pointers, because the line joining them on being produced passes nearly through the pole star) are named α-Ursæ Majoris, and β-Ursæ Majoris. A few very conspicuous stars have proper names; thus, α-Lyræ is also *Vega*, α-Aquilæ is also *Altair*, and so on.

The sun, moon, and planets, in addition to the diurnal motion, are found to move relatively to the fixed stars; so that if they are observed to be near a certain star on one day, they will be found after a few days or weeks to have left the neighbourhood of that star. This motion relative to the fixed stars is called their proper motion, *i.e.*, the peculiar motion which each has in addition to the diurnal motion, which all have in common. It is found that the proper motion of the sun is in a direction opposite to that of the diurnal motion, and that in virtue of its proper motion, it moves in the course of a year once round the great sphere among the stars. It is further found that this proper motion takes place along a great circle, *i.e.*, a circle whose plane passes through the centre of the sphere.

The motions just described are, of course, apparent motions; the diurnal motion of the heavens is due to the real rotation of the earth on its axis, and the proper motion of the sun is due to the actual motion of the earth in her orbit. However, we are here concerned with apparent motions only.

In order to give exactness to our conceptions of these apparent motions, and of the apparent positions of the heavenly bodies with respect to each other, two sets of points and circles are employed; one set fixed relatively to the spectator, the other fixed on the great sphere. It will be observed that the north and south poles of the heavens are fixed in both senses, and therefore belong to each set.

Points and Lines fixed relatively to the Spectator.

(*a.*) The north and south poles of the heavens.

(*b.*) If the direction of the plumb line at the observer's station is produced indefinitely upwards, it gives the *Zenith* of the station; if downward, it gives the *Nadir*.

(*c.*) The great circle whose plane is at right angles to the plumb line is the *Horizon*. This circle is sometimes called the *Rational Horizon*, to distinguish it from the *Visible Horizon*, which is the circle that limits the visible part of the sea.

(*d.*) Any great circle passing through the zenith and nadir is a *Vertical Circle*.

(*e.*) The vertical circle passing through the north and south poles of the heavens is the *Celestial Meridian* of the station; or, more briefly, its *Meridian*.

(*f.*) The vertical circle at right angles to the meridian is the *Prime Vertical*.

(*g.*) The *North* and *South Points* of the horizon are the points in which it is cut by the meridian, the north point being nearest to the north pole of the heavens.

(*h.*) The *East* and *West Points* of the horizon are the points in which it is cut by the prime vertical. The east point is to the right hand of a man who faces towards the north point.

(*k.*) The *Direction of the Meridian* is the line joining the north and south points of the horizon.

(*l.*) The pole above the horizon is the *Elevated Pole*.

FIG. 116.

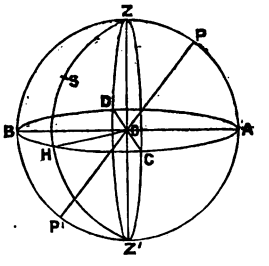
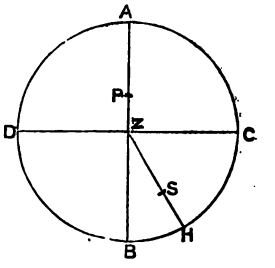


FIG. 117.



These definitions are illustrated by Fig. 116, in which P and P′ are the north and south poles; O the position of the spectator at the centre of the sphere; Z and Z′ the zenith and nadir; PZP′Z′ the celestial meridian; ZCZ′D the prime vertical; ACBD the horizon, of which A and B are the north and south points; C and D the east and west points. In Fig. 116 the north pole is the elevated pole. If S is the position occupied at any instant by a heavenly body, ZSHZ′ is the vertical circle passing through S.

These lines and circles are most conveniently represented by Fig. 117, which shows their projection on the plane of the horizon.*

Points and Lines fixed on the Great Sphere.

(*a.*) The great circle, whose plane is at right angles to the axis of rotation of the great sphere, is the *Equinoctial*, or *Celestial Equator*, or simply the *Equator*.

(*b.*) The equinoctial divides the great sphere into two equal parts. The part in which the North Pole is situated is called the *Northern Hemisphere*, the other part the *Southern Hemisphere*.

(*c.*) It has been stated above that the sun's proper motion takes place along a great circle; that great circle is *the Ecliptic*.

(*d.*) The angle between the ecliptic and the equinoctial is called the *Obliquity of the Ecliptic;* it is an angle of about 23° 28′.

(*e.*) The points in which the ecliptic cuts the equinoctial are the *Equinoctial Points*. The sun passes through one of these points toward the end of March, and in doing so passes out of the southern into the northern hemisphere; that equinoctial point is called the *Vernal Equinox*, or the *First Point of Aries;* it is represented by the symbol ♈. The other equinoctial point, through which the sun passes toward the end of September out of the northern hemisphere into the southern hemisphere, is the *Autumnal Equinox*, or the *First Point of Libra*.

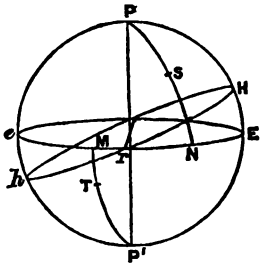
(*f.*) A great circle drawn through the north and south poles of the heavens is a *Declination Circle*. When it is drawn through the centre of a heavenly body, it is called the declination circle of that body.

* It may be mentioned that Z is commonly taken as the projecting point, so that everything above the horizon falls within the circle, and everything below the horizon falls without the circle in Fig. 117.

(*h.*) The *Declination* of a heavenly body is the arc of its declination circle intercepted between its centre and the equinoctial. Declination is reckoned from 0° on the equinoctial up to 90°, and north or south according as the heavenly body is in the northern or southern hemisphere.

(*k.*) The *Right Ascension* of a heavenly body is the arc of the equinoctial intercepted between its declination circle and the first point of Aries. Right ascension is generally reckoned in time, one hour being 15°, and from 0 h. up to 24 h., all round the equinoctial in the direction from west to east, *i.e.*, in the direction opposite to that of the diurnal motion, so that the sun's right ascension is always on the increase.

FIG. 118.



These definitions can be illustrated by Fig. 118, which represents the great sphere of the heavens, P and P′ being the north and south poles; the great circle *e*NE, whose plane is at right angles to PP′, is the equinoctial; the circle γH*h*, inclined to the equinoctial, is the ecliptic. In virtue of the diurnal motion of the heavens, the point N (and with it all the lines and points on the sphere) would move in the direction EN*e*; but in addition to this the sun, in virtue of his proper motion, moves once round the ecliptic in a year in the direction γH*h*. He is at γ about the end of March. If S is the centre of any heavenly body and PSN a quadrant of its declination circle, γN is its right ascension (R.A.), and NS its declination (Dec.); these are the co-ordinates by which its positions on the great sphere are fixed. Thus, suppose that a star is in R.A. 2 h. 30 m. (or 37° 30′) and Dec. 53° N. Measure γN in the direction γE*e* equal to 37° 30′, and draw PN, a quadrant of the declination circle, through N, make NS equal to 57°, then S is the position of the star. Again, suppose a star is in R.A. 22 h. (or 330°) and Dec. 39° S.; measure the arc γE*e*M equal to 330°, draw P′M the quadrant of the declination circle through M, and make MT equal to 39°; T is the position of the star.

The right ascension and declination of the sun are given for every day of the year on pp. I, II, of the "Nautical Almanac." The R.A. and Dec. of about 200 principal stars are given on pp. 290—293 and 311—366 of the "Nautical Almanac."

Positions of Heavenly Bodies relatively to the Spectator.

If we combine Fig. 116 and Fig. 118 into one we obtain Fig. 119, the projection of which on the plane of the horizon is shown in Fig. 120. The dark lines in both belong to Fig. 116, the faint lines to Fig. 118. The apparent motion of the heavens is shown if we sup-

FIG. 119.

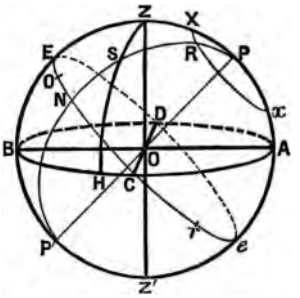
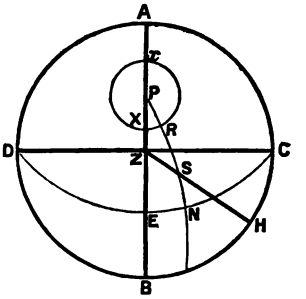


FIG. 120.



pose that the dark lines continue fixed, and that the sphere turns in such a way that ♈ and N are continually moving in the direction CED*e*, and that all points in the heavens move the same way, so that, for instance, a point R describes in a day the circle RX*x*R. The point R will therefore cross the meridian twice a day, viz., at X and at *x*.

(*a*.) The passage of a heavenly body across the observer's meridian is called its *Transit*. The passage which takes place nearest the zenith is called the *Superior Transit*, and very commonly simply *the Transit*. The other passage is the *Inferior Transit*.

(*b*.) The altitude of a heavenly body is the arc of the vertical circle passing through its centre, intercepted between the horizon and the centre of the heavenly body. The altitude of S is the arc SH.

(*c*.) The *Zenith Distance* is the complement of the altitude. The zenith distance of S is ZS.

(*d*.) The *Azimuth* of a heavenly body is the arc of the horizon intercepted between the south (or north) point of the horizon and the vertical circle drawn through the centre of the body. The azimuth of S is the arc BH (or AH). The azimuth is sometimes called the *Bearing*. If BH is an arc of 60°, its azimuth or bearing is 60° east of south or 120° east of north.

(*e*.) The *Polar Distance* of a heavenly body is the arc of its declination circle between the body and the pole. The north polar distance of S is PS, and its south polar distance is P'S. If the pole and the declination are of the same name, both north or both south, the polar distance is 90° − declination, but if they are of different names, one north and the other south, the polar distance is 90° + declination. Thus, if the declination of a heavenly body is 20° S, its north polar distance is 110°, and its south polar distance is 70°.

(*f*.) The *Hour Angle* of a heavenly body is the angle between its declination circle and the meridian. The hour angle of S is the angle ZPS or the arc EN. The hour angle is reckoned east or west, and from 0° up to 180°.

It is plain that the position of S relatively to the spectator is known, if its azimuth and altitude are known, or if its Hour Angle and Polar Distance are known.

Measurement of Time.

Before beginning the subject of the present article, it may be well to premise two remarks.

First. In the present subject arcs of great circles are commonly reckoned in angle, but occasionally they are reckoned in time. When an arc is reckoned in angle, *i.e.*, is said to be an arc of so many

degrees, minutes, and seconds, the meaning is that the arc subtends at the centre of the sphere an angle of so many degrees, minutes, and seconds; if the arc SH (Fig. 119) is one of 57° 35′, the angle it subtends at O is one of 57° 35′. When an arc or angle is reckoned in time one hour means 15°, and consequently angle is reduced to time by dividing it by 15; thus—

$$108° 20′ 37·5″ = 7\text{ h. }13\text{ m. }22·5\text{ s.}$$

Secondly. In the civil reckoning of time, the day is held to begin at midnight, the hours being counted up to twelve at midday, and again up to twelve at the following midnight. In astronomical reckoning the day does not begin till midday (so that civil reckoning is twelve hours in advance of astronomical reckoning), and the hours are reckoned up to twenty-four hours to the following midday. Thus, the instant of time which in civil reckoning is called 5th June 2 h. 40 m. P.M., is called in astronomical reckoning June 5 d. 2 h. 40 m., and 6th June 8 h. 27 m. A.M. in civil reckoning is June 5 d. 20 h. 27 m. in astronomical reckoning.

(*a.*) The *Apparent Sun* is the sun that appears in the heavens.

(*b.*) The *Mean Sun* is an imaginary heavenly body, supposed to move along the equinoctial with the apparent sun's mean or average motion in right ascension.

(*c.*) A *Day* is the interval of time that elapses between the departure of a heavenly body from the meridian and its next return. It is an *Apparent Solar Day*, a *Mean Solar Day*, or a *Sidereal Day*, according as the heavenly body is the Apparent Sun, the Mean Sun, or the first point of Aries. The instant the heavenly body is on the meridian of a station (at superior transit) is noon, viz., apparent noon, mean noon, or sidereal noon at that station.

(*d.*) The *Apparent Solar Time* (or *Apparent Time*) of an instant at a given station is the arc of the equinoctial intercepted at that instant between the declination circle of the apparent sun and the meridian; the arc being measured from the meridian westward and expressed in time. In Fig. 119, if S is the apparent sun, the arc EDeN expressed in time is the apparent solar time of the instant the sun is in that position. Thus, if the arc EN is 40°, EDeN is 320°, or 21 h. 20 m., which is the apparent solar time of the instant.

(*e.*) The last article (*d*) gives the definition of the *Mean Solar Time* (or *Mean Time*) of an instant if for apparent sun we read mean sun. It also gives the definition of the *Sidereal Time* of an instant if for apparent sun we read first point of Aries.

(*f.*) In the last two articles (*d* and *e*), if the meridian is that of Greenwich the times are the Greenwich apparent, mean, and sidereal times respectively. But if it is any other meridian the times are the Local apparent mean and sidereal times respectively. The time of an instant is always reckoned with reference to some assigned meridian.

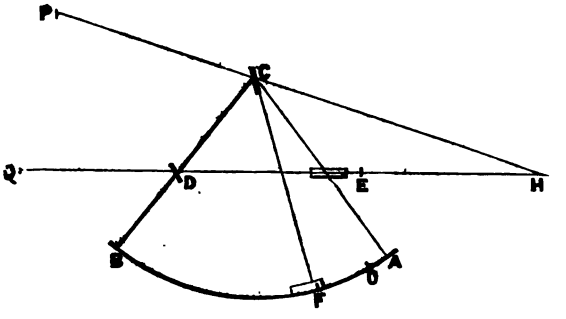
(*g.*) The *Equation of Time* is the difference between mean and apparent solar time, or between the right ascensions of the mean and apparent suns. Its value is given for every day of the year on pp. I, II of the Nautical Almanac.

Sextant and Artificial Horizon.

The sextant consists essentially of a frame ABC, to which is attached an arm CF, moveable round the centre (C) of the graduated arc

AB; at the end of the arm and moveable with it is a mirror C, called the index glass; to the frame work is fixed a glass D, called the

FIG. 121.



horizon glass, the upper part of which is unsilvered, the lower part silvered; so that the upper part is transparent, the lower part a mirror. These glasses should be at right angles to the plane of the instrument. Both the index and horizon glass have near them dark glasses to cut off a superfluity of light in case a very bright object, such as the sun, has to be observed. On the frame near E is a double ring into which a small telescope can be screwed with its axis parallel to the plane of the instrument, and pointing to the line which divides the silvered from the unsilvered part of the horizon glass. In most instruments the ring and with it the telescope can be raised or lowered, so that the axis of the telescope may be directed to points either above or below the line dividing the silvered from the unsilvered part of the horizon glass. The arm CF carries a vernier, of which we will suppose the index to be F. Let O be the zero of the graduated arc, and suppose that when the index is at O the index glass is parallel to the horizon glass, consequently when the index is in any other position, as F, the angle OCF equals the angle between the mirrors. Let P and Q be two distant points, and suppose that a ray of light from P passes into the telescope after reflection at C and D, an image of P will be seen in the telescope: at the same time, suppose that rays of light from Q come through the unsilvered part of D into the telescope, an image of Q will be seen in the telescope. If these two images are made to coincide, it is plain that a ray of light such as PC takes, after reflection at both mirrors, the direction DE. Now under these circumstances, the angle PHQ equals twice the angle between the mirrors (p. 110), and therefore, if the arc OF is graduated at twice its value, the angle PHQ is given by the reading of OF. As P and Q are two distant points, the angle PHQ is sensibly equal to the angle subtended by PQ at the eye, and the sextant enables the observer to measure that angle.

The moveable arm CF is furnished with two screws; first a clamping screw, which holds the arm fixed against any moderate external force except such as is applied by means of the second, which is a tangent-screw, or small-motion screw; on turning the tangent-screw, a slow regulated motion is given to the arm. In using the instrument, it is best to set the index very nearly right by the naked eye, applied near the ring at E, and to clamp the arm. The observer should then screw in the telescope and finish the observation with the tangent screw,

taking care not to work it too far in either direction. The telescope should be carefully focussed before being screwed in.

The arc AB is graduated from O to B and from O to A; the arc OA is graduated up to 5° or 10°; the arc OB up to about 120°. A reading taken on the arc OB is called an "on" reading; one taken on OA is called an "off" reading. In an instrument whose radius is six or eight inches, each degree is divided into six equal parts, so that the reading is taken to 10′ on the limb or graduated arc, and then the vernier enables the observer to read the arc OF true to 10″; the rule being that the divisions read as degrees on the limb are read as minutes on the vernier, while those read as minutes on the limb are read as seconds on the vernier. In taking an "on" reading, the limb is read to the graduation line next before the index, and the vernier reading added to the limb reading. In taking an "off" reading, the limb is read to the graduation line next beyond the index, and the vernier reading is subtracted from the limb reading.

N.B.—The case which holds the sextant generally contains a good many pieces, eye pieces, tubes, dark glass, &c.; the most important of them is a small astronomical telescope, which gives an inverted image of the object seen through it. In the focus of its object glass, the telescope has two pairs of parallel wires, marking out a square space, near the middle of which the images to be obtained should be brought.

The Errors of the Sextant.—It was stated in the last article that the axis of the telescope is parallel to the plane of the instrument, that the index glass and horizon glass are at right angles to that plane, and that when these glasses are parallel, the index F should be at the zero point of the graduated arc O. As none of these conditions may be fulfilled, the instrument is liable to four errors; but the errors are commonly small and can be corrected separately.

(*a.*) To find out whether the axis of the telescope is parallel to the plane of the instrument. Set the instrument so as to bring the images of two stars (which should be 90° or 100° apart) into the field of view of the telescope; set the telescope so that a pair of its wires is parallel to the plane of the instrument; bring the images of the stars into coincidence on one of the wires; and then by a motion of the wrist bring them on to the parallel wire. If they continue to coincide, the axis of the telescope is parallel to the plane of the instrument; if not, the axis requires an adjustment which is made by turning a little screw, which joins the two parts of the ring that holds the telescope.

(*b.*) To find out whether the index glass is at right angles to the plane of the instrument. Set the index at about 60°, bring the eye near the index glass so as to see the arc FB and its image in the index glass. If the arc and its image are continuous, there is no error; but if one appears tilted up so as to make an angle with the other, an adjustment is needed, which is made by means of screws. It would rarely be well for the observer to make this adjustment; if the error is distinctly visible, the instrument should go to the maker.

(*c.*) To find out whether the horizon glass is at right angles to the plane of the instrument. Set the instrument at zero; look at any well-defined distant object through the telescope; two images will be seen, one directly, the other by reflexion in the mirrors. By turning the tangent screw, make the one image pass over the other; if in passing the one image coincides with the other, the horizon glass is at right angles to the plane of the instrument; if not, the glass needs adjustment, for making which means are provided. Strictly speaking, the coincidence of the images would only prove that when the lines in

which the mirrors cut the plane of the instrument are parallel, their planes are parallel; but then the index glass has been found to be very nearly, if not exactly at right angles to the plane of the instrument. It is also to be observed, that if the above errors (*a*, *b*, *c*) are small, the errors they cause in the measured angle are very small.

(*d.*) To find out whether the reading is zero when the mirrors are parallel, *i.e.*, whether there is an *index error*. Referring to Fig. 116, it will be seen that if PC and QD are parallel, the angle at H is zero, and consequently the angle between the mirrors is zero, *i.e.*, the mirrors are parallel; this will be the case when the rays PC and QD come from the same very distant point. Now in such a case the rays which pass directly from the point into the telescope will form one image, and those which fall on C and pass into the telescope after reflexion at C and D, will form another image; consequently, if we set the instrument with C and D nearly parallel, we shall see both these images, and if with the tangent screw the images are brought into coincidence, the mirrors must then be parallel, and the reading of the instrument, if not zero, is the index error, "on" or "off" according as the index falls between O and B or between O and A. If the index error when thus found is large, it should be reduced by shifting the horizon glass; but as it cannot be permanently corrected by mechanical means, its value must be found from time to time by observation, and for this purpose, though the above method is theoretically exact, the following is found to be best. Having turned down the requisite dark glasses, and having focussed and screwed in the telescope, set the index at 30′ on. If the observer now looks at the sun through the telescope, he will see two images of it; with the tangent screw he brings them into exact contact, and reads the graduated arc; he then sets the instrument at 30′ off, and goes through the same process. Half the difference of the readings is the index error; it is "on" or "off" according as the "on" or "off" reading is the greater. An "on" index error has to be subtracted from, an "off" index error has to be added to all readings of the graduated arc.

Ex. The readings for index error are found to be 25′ 40″ on, and 38′ 10″ off; an angle being measured with the same instrument, the reading was 37° 15′ 20″; what was the true value of the angle?

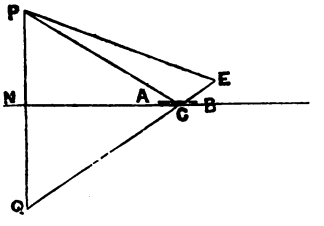
		38′	10″	off.
		25	40	on.
	2)	12	30	
Index error.....		6	15	off.
Reading of instrument	37°	15′	20″	
True value of angle	37°	21	35	

N.B.—If the readings are both "on" or both "off," the index error is half their sum, and is "on" or "off" according as the readings are "on" or "off."

The artificial horizon is simply a little mercury, which just covers the bottom of a shallow dish of wood or iron. A glass cover is commonly used to protect the surface of the mercury from the wind. The surfaces of the glass used should be strictly parallel. Of course any liquid will supply a horizontal reflecting surface, which is the essential part of the artificial horizon.

When the observer finds the angle of vertical elevation of a point, the angle he actually measures is that subtended at his eye by the line joining the point and its image formed by reflexion in the mercury. Now the image of a point seen in a plane reflector is formed on the line drawn from the point at right angles to the plane, the point and its image being at equal distances from the plane, but on opposite sides of it. Let AB be the surface of the mercury; P the point whose angle of vertical elevation (or *altitude*) at E, the eye of the observer, is required. Draw PNQ at right angle to BA produced, and make QN equal to PN; Q is the image of P; and the angle

FIG. 122.



measured by the observer is PEQ. Now, if P is so distant that the angle EPC is insensibly small, the angle PEQ equals PCQ, and the half of PEQ equals the half PCQ., *i.e.*, PCN, which is the angle of vertical elevation of P at C, and therefore at E; since in this case the distance CE has no sensible effect on the angle.

The following important points may be noticed here:—

(*a.*) The sextant will not enable us to measure PEQ, if it is an angle of more than about 120°. Again it is found highly inconvenient to measure PEQ, if it is less than about 30°. Consequently when sextant and artificial horizon are used the observer cannot measure the altitude of a heavenly body which is less than about 15°, or greater than about 60°.

(*b.*) The image formed by reflexion in the mercury is inverted. This is a point of great importance when the altitude of the sun is to be measured. For though the altitude of the centre is required, it is found best to measure the altitude of the upper or lower end of a vertical diameter, or, as it is called, the altitude of the upper or lower limb. This being so, it is to be remembered that the image of the sun reflected from the mercury when seen in the inverting telescope is erect; for the image has been inverted by the mercury, and again by the telescope. The

FIG. 123.

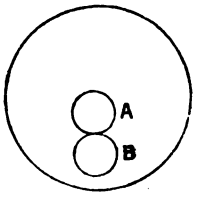


image reflected from the mirrors is inverted. Let the observer see in the telescope two images of the sun exactly in contact, and let A be

the image reflected from the mercury and B the image reflected from the mirrors; the reading of the instrument will give the double altitude of the lower limb. Of course, if B had been the image reflected from the mercury, the reading of the instrument would give the double altitude of the upper limb.

Instrumental Parallax.—Referring to Fig. 116, let h denote the perpendicular distance of C from DE, and a the distance of Q from C, the number of seconds in the angle CQE is

$$\frac{h}{a \text{ Sin } 1''}$$

e.g., if h and a were 2 inches and 100 feet respectively, the angle CQE contains 5′ 44″, and if the observer tried to determine the index error of the instrument by the point Q, his determination, if otherwise correct, would be wrong by 5′ 44″.

Again, referring to the same figure, in measuring the angle subtended by the points P and Q, at the eye of the observer, the angle required is PEQ, while that given by the instrument is PHQ. The required angle is greater than PHQ by a number of seconds given by the formula—

$$\frac{h \text{ Sin } (A - PHQ)}{b \text{ Sin } 1'' \text{ Sin } A},$$

in which the perpendicular distance of C from DE is denoted by h, the distance of P from C by b, and the angle CED by A. Of course the above formula gives a negative result if PHQ is greater than A.

Thirdly, referring to Fig. 117, the vertical elevation of P at the eye is less than half the measured angle between the point and its image formed by reflexion in the mercury by a number of seconds given by the formula—

$$\frac{CE. \text{ Sin } PEQ}{2PC \text{ Sin } 1''}.$$

These three angles are all of the nature of parallax, *i.e.*, the difference between an angle as it would be measured at a standard point, and as it is actually measured at a point not coinciding with the standard point. It is to be observed (1) that the above formulæ are obtained on the supposition that the corrections, whose value they give, are small; (2) that the corrections have no sensible existence when the points observed are heavenly bodies.

Correction of Measured Altitude.—When the double altitude of a limb of the sun has been measured, the following corrections are required:—

(*a.*) Add or subtract index error, to get true reading.
(*b.*) Divide by 2 to get the measured altitude of upper or lower limb.*
(*c.*) Take out the semi-diameter from the Nautical Almanac, p. II, and subtract or add it, according as the altitude of the upper or lower limb has been measured. This gives the measured altitude of the centre.
(*d.*) Take out the atmospheric refraction ("Chambers," p. 428), and subtract it.

* At sea the dip of the horizon has to be subtracted instead of dividing by 2; but we are not here concerned with the methods used at sea.

(*e.*) Take out the sun's parallax in altitude ("Chambers," p. 429), and add it.

The result is the correct altitude of the centre.

The following remarks may be made with regard to these corrections. Those marked (*a*) and (*b*) have been already explained. In regard to (*c*) the semi-diameter of the sun is the angle subtended at the earth's centre by the semi-diameter of the sun's disc.

In regard to (*d*), the correction for *Atmospheric Refraction*, it may be mentioned that when a ray of light passes from a vacuum into a transparent medium it is bent (or refracted) from its original direction, and consequently the eye, being in the atmosphere, sees a point in space displaced from the position in which it would be seen if there were no atmosphere. This displacement is called the *Atmospheric Refraction;* it takes place in a vertical plane and in such a manner as to increase the apparent altitude of the point; the amount of the displacement becomes less as the altitude is greater, and at a given altitude it is slightly different in different states of the atmosphere. The numerical value of the displacements are given in Tables of Atmospheric Refraction.

(*e.*) The correction for *Parallax* is made in order to reduce an altitude measured on the surface of the earth to the altitude as it would be measured at the centre, which is the standard station to which all measurements are referred. The radius of the earth has a sensible magnitude in comparison with its distance from the sun, and therefore in the case of the sun this correction is necessary. If the sun is on the horizon the parallax is about 9″; this is called the *Horizontal Parallax* of the sun; it is the angle subtended by the semi-diameter of the earth's disc if seen at the distance of the sun. In any other position the parallax equals 9″ × (cos. altitude); this is called the *Parallax in Altitude.*

When the double altitude of a star has been measured, the correction is made in the same way as in the case of the sun, except that a star has no semi-diameter, and no parallax, so that the corrections (*c*) and (*e*) are omitted.

Ex. On the afternoon of September 15th, the double altitude of sun's upper limb was measured as 49° 18′ 50″; the readings for index error were 17′ 40″ on, and 46′ 10″ off; correct the measurement.

	46′ 10″	off
	17 40	on
	2)28 30	
Index error	14 15	off

Reading of instrument		49°	18′ 50″
Index error.....		0	14 15 off
		2)49	33 5
Upper limb.....		24	46 32·5
Semi-diam. (Sept. p. II, N. A.)		0	15 57·1
		24	30 35·4
Refraction.....	2′ 5″*		
Parallax	0 8		
	1 57		1 57
Corrected altitude of centre		24	28 38

Ex. On the same evening with the same instrument, the double altitude of α-Aquilæ (*altair*) was measured as 91° 28′ 40″. Correct the measurement—

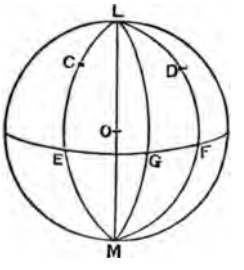
Reading of instrument		91°	28′ 40″
Index error		0	14 15 off
		2)91	42 55
		45	51 27·5
Refraction.....		0	0 55·3
Corrected altitude of star		45	50 32

Definition of Latitude and Longitude.

The latitude and longitude of a station as shown on a map of the world or on a terrestrial globe, may be defined as follows:—

Let the annexed figure represent the earth regarded as a sphere, whose centre is O; L and M are the north and south poles, EGF the

Fig. 124.



great circle at right angles to LM is the equator; any great circle drawn through the poles is a meridian, and if LGM passes through Greenwich it is the meridian of Greenwich; let D be any station whose meridian

* Throughout this chapter, the mean refraction, given on p. 428 "Chambers," has been used. If great exactness is required, it should be corrected for pressure and temperature by the table on p. 429.

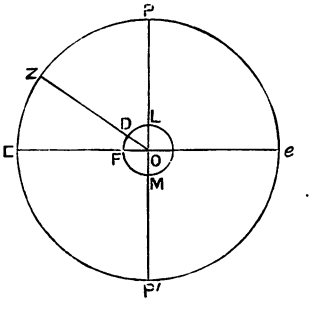
is LDFM, then DF reckoned in angle is the latitude of D, and GF likewise reckoned in angle is the longitude of D. These two arcs (or angles), GF and FD are in fact co-ordinates by which the position of D on the earth's surface is fixed relatively to the equator and to some one meridian, which English geographers assume to be the meridian of Greenwich. Longitude is reckoned eastward of Greenwich up to 180°, and also westward of Greenwich up to 180°; latitude is reckoned from the equator up to 90° north, and from the equator up to 90° south. Thus, if GF is an arc of 20°, and FD an arc of 40°, D is a station in latitude 40° N. and longitude 20° E. A little consideration will show that the position of any point relatively to the equator and to the meridian of Greenwich is thus determined without any ambiguity. Suppose that a station is in longitude 70° W. and 50° N., measure off the arc GE westward from G and equal to 70°; through E draw a great circle LEM, and on it measure EC northward from E and equal to 50°; C is the position of the station.

It will be observed that the arc GF measures the angle GLF; so that, for example, if GF is an arc of 20°, GLF is an angle of 20°; consequently the longitude of D is the angle between the meridian of D and the meridian of Greenwich.

An observer at any station, say at D, who wishes to find his latitude and longitude, wishes to find the angular value of the arcs DF and GF: he has (ordinarily) no means of doing this except observation of the heavenly bodies. It is therefore necessary to define the latitude and longitude of his station somewhat differently from what has been above given.

First, as to latitude:—Let LDFM, Fig. 125, represent the meridian of the station D in Fig. 124, O being the centre of the earth, which is still supposed to be a sphere. With centre O and any large radius describe the circle PEP′*e*, which will represent the section of the great sphere made by the plane of D's meridian, the circle PEP′*e*, therefore, represents the celestial meridian of D. Through O draw QLP, QDZ,

FIG. 125.

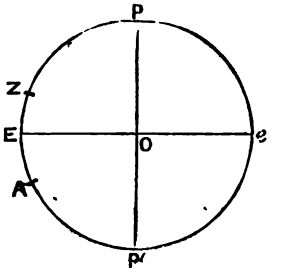


QFE, and OMP′; P and P′ are the north and south poles of the heavens, Z is the zenith of D, E is the zenith of F. If EO is produced to *e*, E and *e* are the points in which the celestial equator or equinoctial cuts the celestial meridian, and, as the sun is near the zenith of F at midday, E is the point near which the sun crosses the meridian at midday. P, E, P′, *e* are in fact the same points as those indicated by the same letters in Fig. 119. It is plain that the arcs ZE and DF measure the angle DOF, they will therefore contain the same number of degrees,

minutes, and seconds. We thus obtain the following definition :—*The latitude of a station is the arc (reckoned as an angle) of the celestial meridian intercepted between the zenith of the station and the equinoctial.*

In arriving at this definition, we have made use of the assumption that the earth is a sphere, but it does not depend on that assumption; the arc ZE is the latitude of D without reference to the precise shape of DF. The student should therefore fix his attention on the celestial meridian and make himself familiar with the following construction :— Let PEP′*e* be the celestial meridian of the station, P and P′ the north and south poles of the heavens, E and *e* the points in which the meri-

FIG. 126.



dian is cut by the equinoctial, E being the point near which the sun passes at noon. If the latitude of the station is north, the zenith will be in EP; if south in EP′, and under any circumstances the arc EZ, reckoned in angle (*i.e.*, in degrees, minutes, and seconds), is the latitude of the station whose zenith is Z.

Secondly as to the longitude.—Referring to Fig. 124, suppose a sphere described with centre O and radius much greater than OL to represent the great sphere, and suppose the planes of LFM, LGM, and LEM produced to cut the surface of this sphere. This will give rise to Fig. 127, in which PKP′ is the celestial meridian of D, whose zenith is B, PGP′ is the celestial meridian of Greenwich, and PHP′ is the celestial meridian of C, whose zenith is A; P and P′ are the north and south poles of the heavens, and HGK is the equinoctial. Now the extension of the planes does not change the angles between them; consequently the angle GPB (which equals the angle GLD, Fig. 124) is the longitude of the station (D), whose zenith is B, and, of course, the arc GK in angle is also the longitude of that station. In like manner the angle GPA (or the arc GH in angle) is the longitude of the station (C), whose zenith is A.

FIG. 127.

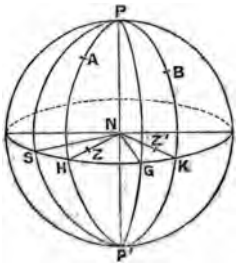
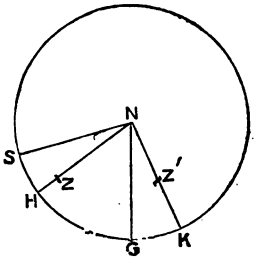


FIG. 128.



Let us now suppose these circles to be projected on the plane of the equinoctial as shown in Fig. 127, where P is projected into N; PK, PG, PH into NK, NG, NH; and A and B into Z and Z'. If the plane of the equinoctial is brought into the plane of the paper, we manifestly obtain Fig. 128, which is found to be by far the most convenient way of representing the circles of Fig. 127. It will be observed that the angles are not altered by the projection, so that GNK (or GK in angle) is still the longitude of the station whose zenith is Z' (or B).

Hitherto we have spoken of longitude as being reckoned in angle. It is, however, frequently (or even usually) reckoned in time; so that, for instance, a station in longitude 51° 42' 27" W., might be (and indeed is usually) said to be in longitude 3h. 26m. 49·8s.

Let S be the position of the mean sun at any instant, and let the angles SNH, SNG, SNK be expressed in time; they are respectively the local mean time of the same instant at Z, at Greenwich, and at Z'. Now we see that

$$\text{GNH} = \text{GNS} - \text{HNS}$$
$$\text{and GNK} = \text{KNS} - \text{GNS},$$

ie., the longitude of a station west of Greenwich equals the Greenwich mean time minus the local mean time of the same instant; and the longitude of a station east of Greenwich equals the local mean time minus the Greenwich mean time of the same instant. The same conclusion would follow if S were the apparent sun, but then SNH, SNG, SNK are the apparent times of the same instant at the three stations respectively; and the same conclusion would also follow if S were the first point of aries, but then the same angles are the sidereal times of the same instant at the three stations respectively. Hence the rule is: the longitude of a station is the difference between the time of any instant at the station and the time of the same instant at Greenwich; the longitude is west if the local time is behind, and east if in advance of Greenwich time; the times may be either both apparent solar time, or both mean solar time, or both sidereal time. It is to be observed (*a*) that the mean sun moves through 15° of longitude in one mean solar hour, and that the first point of Aries moves through 15° of longitude in one sidereal hour; (*b*) if mean solar time is given in civil reckoning, it should be turned into astronomical reckoning.

Ex. A phenomenon occurred at local mean solar time, 3rd April, 10 h. 21 m. 5 s. A.M.; the Greenwich mean solar time of the same instant was 31 m. 43 s. past 12 on the afternoon of April 3rd.

Expressing both the times astronomically we have—

G.M.T.	April 3 d.	0 h.	31 m.	43 s.
L.M.T.	April 2	22	21	5
Therefore the longitude of station is		2	10	38 W.

Determination of Latitude.

Latitude by Sun's Meridian Altitude.—The altitude of a heavenly body increases from its rising till it reaches the meridian; it then decreases till its setting. The observer makes use of this fact as follows: A few minutes before noon, having turned down the requisite dark glasses, having set the instrument, and having focussed and screwed

in the telescope, he brings the two images of the sun into contact on the upper limb (mercurial sun below); as the sun is still rising, an overlap will be formed if the images are watched for a few minutes; the observer, however, destroys the overlap as soon as any trace of it appears, so as to keep the two images in exact contact so long as there is any tendency to form an overlap. After a time the two images begin to separate, showing that the sun has begun to fall in the heavens; the observer then reads the instrument and thereby obtains the greatest, *i.e.*, the meridian altitude of the sun. The latitude is then inferred thus:—

(*a.*) Correct the observed altitude.
(*b.*) Subtract the altitude of the centre from 90° so as to obtain the zenith distance, and mark it N or S, according as the zenith was north or south of the sun.
(*c.*) Take out the declination from the Nautical Almanac (p. I or II of each month) and mark it N or S, according to the entry in the almanac.
(*d.*) If the entries are both N or both S, the latitude is the sum, and is north if both are marked N, but south if both are marked S. If one entry is marked N and the other S, the latitude is their difference, and is north if the larger entry is marked N, but south if the larger entry is marked S.

It is to be observed (1) that if the observer faces south when making the observation, his zenith is north of the sun; but if he faces north, his zenith is south of the sun; (2) that if the observer takes the time of the observation from the chronometer, he knows (at least approximately) the Greenwich mean time of the observation, and then takes out the declination of the sun from p. II of the Nautical Almanac. If he does not use the chronometer, he knows that the observation was made at local apparent noon; he also knows the longitude approximately; he therefore knows approximately the Greenwich apparent time, and takes out the declination from p. I of the Nautical Almanac.

Ex. On 1st Dec., 1881, the observer facing south measures the double meridian altitude of the sun's upper limb to be 96° 32′ 40″; the longitude is approximately 2 h. 3 m. 50 s. E; the index error of the instrument is 3′ 20″ on; find the latitude of the station.

(*a.*)	Reading of instrument }	96°	32′	40″	
	Index error }	0	3	20	on
		2)96	29	20	
		48	14	40	
	Semi-diam. (p. II)	0	16	16	
		47	58	24	
	Refraction and parallax (Chambers, p. 428, 9)	0	0	45	
		47	57	39	
(*b.*)		90	0	0	
	Zenith distance	42	2	21	N
(M. T.)				N	

(*c.*) Greenwich apparent time of observation Nov. 30 d 21 h. 56 m. 10 s. approximately.

Sun's declination (p. 1, Novem.)....	21°	52′	23″	S
(*d.*) First entry.....	42°	2′	21″	N
Second entry	21	52	23	S
Latitude	20	9	58	N

It is easy and instructive to verify this result by drawing a figure as follows:—Draw a circle to represent the meridian of the station as in Fig. 126; mark P, P′, the north and south poles of the heavens, and E, *e*, the points at which the equinoctial cuts the meridian; measure off EA equal to 21° 52′ 23″ to to the south of E (as the declination is south). A is the point at which the sun crosses the meridian; from A measure AZ northward (as the zenith is north of the sun) equal to 42° 2′ 21″; Z must fall to the north of E, and ZE must equal 20° 9′ 58″, the latitude of the station which is north.

Latitude by Meridian Altitude of a known Star.—In making the observation we have to deal with two images of the star which are merely bright points, and which must be brought into coincidence, or rather, for the instrument will not be quite without motion, brought together so that the one image passes through the other. As this is done before the star comes to the meridian, the mercurial image tends to rise in the field of view of the inverting telescope; the images must, however, be kept together by the tangent screw, until the mercurial image is seen to fall below the other; when this takes place it is known that the star is descending in the heavens, and therefore has passed the meridian; the reading of the instrument, after correction, will give the meridian altitude of the star. If the star observed is one of those given on pp. 290—293, N. A., its declination is known from the Nautical Almanac. The latitude of the station is inferred from the meridian altitude and the declination in just the same way as in the case of the sun.

Ex. On Feb. 10th, 1881, an observer looking north measures the double meridian altitude of α Geminorum (*Castor*) as 69° 45′ 20″; the index error of the instrument is 7′ 20″ on; find the latitude of his station. It will be found that the corrected altitude of the star is 34° 47′ 38″; also by Nautical Almanac, pp. 291 and 333 the declination of the star is 32° 8′ 48″ N. Hence—

First entry.....	55°	12′	22″	S.
Second entry.....	32	8	48	N.
Latitude	23	3	34	S.

This result can be verified by drawing a diagram as above explained.

N.B.—If a planet is observed the process is the same, but there are corrections for semi-diameter and parallax, and the declination must be found from a knowledge of the approximate Greenwich mean time of observation.

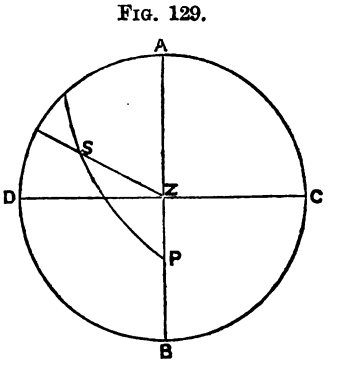
The method, above explained, of finding the latitude by a meridian altitude is the fundamental method. It has the great advantage that the requisite calculation is short and easy. On the other hand, it is subject to the drawback that if the sun—which is commonly used—

is behind a cloud when on the meridian, the observation cannot be repeated that day. In the case of a star the drawback is not so considerable; for though the observer may fail with one star, he may succeed with another. There are, however, methods of determining the latitude by observations off the meridian, which will be found in works on nautical astronomy. One very valuable method is that of the pole star off the meridian; the observation can be made at any time of night, and at any place on land between the latitudes of 15° and 60° N., supposing a sextant of the usual construction to be employed. The proper tables for deducing the latitude are given in the Nautical Almanac, pp. 477, 8, 9, and rules for using them with a worked example on p. 514 (1881).

Determination of Longitude and Watch Error.

In finding the longitude, watch error, and deviation of the compass, an altitude must be measured of the sun or of a star off the meridian. Now if a triangle is drawn whose angular points are the pole (P), the zenith (Z), and the sun or star (S), we have a triangle SPZ, whose sides are known, and of which we have to calculate an angle. It is highly convenient therefore to have this triangle definitely before the calculator, and for this purpose it is well to draw the annexed figure, in which the circle represents the horizon, and A, B, C, D its north, south, east, and west points, placed as in a map, viz., north point at top. Then AB is the meridian, CD the prime vertical projected on the plane of the horizon, and intersecting in Z the projection of the zenith. If the observer is in the northern hemisphere, the elevated pole (P) is between A and Z; if in the southern hemisphere, between B and Z. For an observation made

Fig. 129.



when the sun or star is to the east of the meridian, S is within the semicircle ACB; when to the west, within the semicircle ADB. The above diagram, if S is the sun, is adapted for an afternoon observation made in the southern hemisphere. A diagram thus drawn we shall speak of as "the usual figure." If the sun or star is in the act of rising or setting S will, of course, be on the circumference of the circle ABCD.

The Principle of Determining the Longitude of a station is very simple. The altitude of a heavenly body is measured at a certain instant of Greenwich mean time. Now, three things are known, viz.

(*a*), the declination and therefore the *polar distance* (PS in Fig. 129) of the heavenly body; (*b*), the latitude of the station, and therefore the arc of the meridian from the pole to the zenith (PZ) or the *co-latitude* of the station; (*c*), the altitude, and therefore the *zenith distance* (ZS) of the heavenly body at the instant. Now the three sides being known the triangle PZS is known, and consequently the hour angle SPZ can be calculated. This is most conveniently done by the formula*—

$$\text{Sin}^2\tfrac{1}{2}\text{SPZ} = \frac{\text{Sin}\,(s - \text{PZ})\ \text{Sin}\,(s - \text{PS})}{\text{Sin PZ Sin PS.}}$$

when s denotes the semiperimeter of the triangle. The logarithmic form of this equation is—

$$2 \log \text{Sin}\,\tfrac{1}{2}\text{SPZ} = \log \text{Sin}\,(s - \text{PZ}) + \log \text{Sin}\,(s - \text{PS}) + 10 - \log \text{Sin PZ} + 10 - \log \text{Sin PS},\dagger$$

the logarithms being tabular logarithms. Now, from the hour angle SPZ, we can infer the local mean time of the instant at which the observation was made, and we know from the chronometer the Greenwich mean time of the instant, therefore we can infer the longitude as above explained. It is to be observed (1) that it is always known whether the sun or star is to the east or west of the meridian at the time of observation; (2), that when the hour angle has been found, the way of inferring the local mean time is different, according as the heavenly body is the sun or a star.

Problem.—To find the local mean time of the instant when the sun has a given hour angle.

(*a.*) Divide the hour angle by 15 to reduce to time; the quotient is the local apparent time if the hour angle is west; the quotient subtracted from 24 h. gives the local apparent time if the hour angle is east.

(*b.*) Take out the equation of time from the Nautical Almanac. If the G.M.T. of the instant is known, the equation of time will be taken from p. II; but if only the longitude is known the G.A.T. must be inferred, and then the equation of the time must be taken from p. I. It is enough if G.M.T. or longitude be known approximately.

(*c.*) Add the equation of time to, or subtract it from, the local apparent time according to the rule at the top of the column on p. I Nautical Almanac.

The result is the local mean time.

Ex. The sun's hour angle, at a certain station, was found to be 43° 18′ 27″ on the morning of the 8th of October, at an instant when the G.M.T. was approximately Oct. 7 d. 15 h. 43 m.; find the local mean time of the instant.

	15)43°	18′	27″
Hour angle	2 h.	53 m.	13·8 s. east.
	24		
Local apparent time	21	6	46·2
Equation of time (to be subtracted)..		12	24·5
Local mean time ..... Oct. 7 d.	20 h.	54 m.	21·7

* There are similar formulæ for $\cos^2\frac{1}{2}$SPZ and $\tan^2\frac{1}{2}$SPZ, either of which might be used.

† 10 − log x is called the arithmetical complement of log x; thus log sin

To find the Longitude of a Station by an Observed Altitude of the Sun.—The observer takes the sextant, his assistant the chronometer, which shows Greenwich mean time. The observation should be made when the sun is not less than about 20° above the horizon, and at least two or three hours from—say to the east of—the meridian; other conditions being the same, the more remote the sun is from the meridian the better. The observer brings the two images of the sun to a very small overlap on the lower limb (mercurial sun at top); he waits for a few seconds, and at the instant the overlap disappears he calls "stop," and reads the instrument, while the assistant notes the Greenwich mean time of the instant at which the observer called "stop." The observation, when entered, stands thus:—

At G.M.T. Feb. 2 d. 19 h. 2 m. 43 s., d. alt. sun's LL. was 84° 24′ 50″.

The longitude might be inferred from this observation; but it is usual to make three observations in quick succession, and to infer the longitude from the means. Thus, suppose that two observations were taken directly after that above given, there are then then three observations such as the following:—

G.M.T.	Feb.	2 d.	19 h.	2 m.	43 s.	d. alt. sun's LL.	was	84°	24′	50″
,,	,,		19	4	12	,,	,,	85	2	30
,,	,,		19	5	50	,,	,,	85	39	40
		3)	57	12	45		3)	255	7	00
			19	4	15			85	2	20

The observation which has to be calculated is, therefore—

At G.M.T. Feb. 2 d. 19 h. 4 m. 15s d. alt. sun's LL. was 85° 2′ 20″.

If the sun is to the west of the meridian the process is exactly the same, except that the observer brings the two images of the sun to a very small overlap on the upper limb (mercurial sun below); so that the double altitude of the lower limb is observed in the morning, that of the upper limb in the afternoon.

The steps of the process by which the longitude is inferred are as follows:—

(*a.*) Draw the "usual figure" (p. 189) so that the triangle on which every thing depends may be distinctly before the calculator.

(*b.*) Correct the measured altitude and subtract it from 90°, so as to obtain the zenith-distance of the sun's centre (ZS).

(*c.*) Subtract the known latitude from 90°, so as to obtain the co-latitude (ZP).

(*d.*) Take out the declination from p. II of the Nautical Almanac, obtain from it the polar distance PS; bearing in mind that polar distance equals 90° − declination, if pole and declination are both north or both south, and that polar distance equals 90° + declination, if of pole and declination one is north and the other south.

(*e.*) Calculate the hour angle SPZ by the above formula, viz.:—

17° 51′ 20″ is 9·486 5982, and its arithmetical complement is 0·513 4018, which is easily written down by the rule:—subtract the first right-hand digit from 10, and the rest from 9.

$$2 \log \text{Sin } \tfrac{1}{2}\text{SPZ} = \log \text{Sin } (s - \text{PZ}) + \log \text{Sin } (s - \text{PS}) + \text{ar. c. log Sin PZ} + \text{ar. c. log Sin PS.}$$

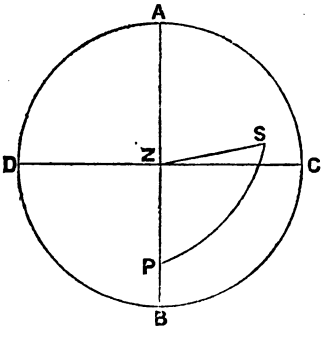
(*f.*) From the hour angle infer the local mean time of the observation, as above explained.

(*g.*) By comparison of the local mean time of observation with the Greenwich mean time of the observation, infer the longitude.

Ex. In latitude 23° 3′ 40″ S on the morning of the third of February, the Greenwich chronometer showed 7 h. 4 m. 15 s., when the double altitude of the sun's lower limb was 85° 2′ 20″; the readings for index error were 29′ 10″ off and 35′ 30″ on. Find the longitude.

(*a.*) The usual figure is drawn thus:—

FIG. 130.



(*b.*) Correct the measured altitude

	35′	30″	on
	29	10	off
2)	6	20	
Index error....	3	10	on, to be subtracted.

Reading of the sextant	85°	2′	20″	
Index error		3	10	on
	2)84	59	10	
Measured alt. ⊙'s LL.	42	29	35	
Semi-diam. (p. ii, N.A.)		16	15·4	
	42	45	50·4	
Paral. and Ref. (Chamb. pp. 428, 9) ..			56	
Corrected altitude	42	44	54	
	90			
Zenith distance	47	15	6	

(*c.*)

Latitude of station	23°	3′	40″	S.
	90			
Co-latitude, PZ	66	56	20	

(*d.*) Determine sun's (south) polar distance. The Greenwich mean time of observation reckoned astronomically is Feb. 2 d. 19 h. 4 m. 15 s.

Sun's declination at G.M.N. Feb 2 d. ..	16°	40′	52·7″	S.
Diff. for 19 h. 4 m. 15 s.		14	1	
Declination at time of observation	16	26	52	S.
	90			
South polar distance, PS.....	73	33	8	

(*e.*) Calculate the hour angle, SPZ.

ZS....	47°	15′	6″		
PZ....	66	56	20	ar. c. log Sin PZ ..	0·0361708
PS....	73	33	8	ar. c. log Sin PS ..	0·0181460
2)187	44	34			
s ..	93	52	17		
s − PZ..	26	55	57	log Sin (s − PZ)..	9·6560412
s − PS..	20	19	9	log Sin (s − PS)..	9·5406415
				2)19·2509995	
				log sin ½SPZ	9·6254998

Hence, ½SPZ.....	24°	58′	20″
			2
Hour angle, east	49	56	40

(*f.*) and (*g.*) Determine local mean time and thence longitude.

	15)49°	56′	40″	
	3 h.	19 m.	46·7 s.	
	24			
Local apparent time	20	40	13·3	
Equation of time (p. II, N.A.)		14	5·4	add
Local mean time ..... Feb. 2 d.	20 h.	54 m.	19 s.	
Greenwich M.T..... Feb. 2 d.	19	4	15	
Longitude	1	50	4	

Hence the required longitude of the station is—

1 h. 50 m. 4 s. E, or 27° 31′ 0″ E.

N.B.—It has been assumed that the G.M.T. of the observation was Feb. 2d 19 h. 4 m. 15 s.; it might just as well have been assumed that the G.M.T. was Feb. 3d 7 h. 4 m. 15 s. If this had been done the longitude would have come out about 10 h. 10 m. W. In practice this ambiguity would never occur.

Problem.—Given the hour angle of a known star* at any instant to infer the local sidereal time of the instant.

Let P be the pole, the circle denoting the equinoctial as in

FIG. 131.

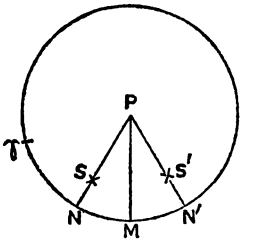


Fig. 128. PM is the meridian of the station, Υ the position of the first point of Aries at the instant under consideration; then, ΥM, expressed in time, is the local sidereal time of the instant. Let S be a star whose hour angle is west, and equal at the instant to MN; and let S′ be another star, whose hour angle is east, and equal to MN′ at the instant. Now it is plain that—

$$\Upsilon M = \Upsilon N + NM = \Upsilon N' - N'M.$$

In other words, the local sidereal time equals

Right ascension of star + its hour angle if west,
or Right ascension of star − its hour angle if east.

A sum in the former case, a difference in the latter; but 24 h. must be struck off the sum if greater than 24 h., and 24 h. must be added to the right ascension if the difference would otherwise be negative. The above rule will then answer for all cases.

Ex. The hour angle of α Arietis was 55° 10′ 18″ E. on Nov. 10th, 1881. What was the local sidereal time?

R.A. α Arietes (N.A., p. 323)	2 h.	0 m.	33·27 s.
Hour angle, 55° 10′ 18″	3	40	41·20 E.
Local sidereal time required	22	19	52·07

Here, the hour angle being east, must be subtracted from the right ascension; and the right ascension must be increased by 24 h., because it is less than the hour angle.

Problem.—Given the local sidereal time at any instant to infer the local mean time at the same instant. For the solution of this problem we may use the entries in the column on page II of the Nautical Almanac, marked "sidereal time," *i.e.*, sidereal time of Greenwich mean noon. Now the sidereal clock gains on the common clock 3 m. 56·555 s. of sidereal time in a day, or 9·857 s. in an hour; hence, to find the sidereal time of mean noon at any other station, we must increase the sidereal time of Greenwich mean noon at the rate of 9·857 s. per hour of west longitude, and diminish it at the same rate per hour of east longitude. It will be observed that a small error in the longitude will not sensibly affect the amount of this increase or decrease, and consequently that an approximate knowledge of the longitude is

* By a known star is here meant a star whose right ascension and declination are given in the "Nautical Almanac;" they are found on pp. 319—366.

sufficient for the solution of the problem. We can, therefore, proceed as follows:—

(*a.*) With the longitude as approximately known, determine the sidereal time of local mean noon.

(*b.*) Subtract the sidereal time of local mean noon from the given sidereal time of the instant, but the latter must be increased by 24 h. if less than the former. The result is the interval of time elapsed since local mean noon expressed in sidereal units.

(*c.*) Express the interval in mean solar units by the table of time equivalents (Nautical Almanac, pp. 484—5), the result is the local mean time of the instant.

Ex. Find the local mean time of the instant on the morning of January 3rd, when the hour angle of Castor is 47° 18′ 12″ W., at a station whose longitude is approximately 2 h. 18 m. E.

(*a.*) Sidereal time G.M.N (p. II) ..	18 h.	49 m.	2·43 s.
Deduct for 2 h. 18 m. east long.	0	0	22·67
Sid. T. of local M.N.	18	48	39·76
(*b.*) Hour angle west	3 h.	9 m.	12·80 s.
R.A. Castor (N.A., p. 333)	7	27	3·35
Local sid. time of instant.....	10	36	16·15
Sid. time of local M.N.	18	48	39·76
Sidereal interval since M.N.....	15	47	36·39

(*c.*) Convert the units by p. 484–5, N.A.

15 h.	14 h.	57 m.	32·5566
47 m.	0	46	52·3002
36 s.	0	0	35·9017
·39	0	0	00·3889
	15	45	1·15

Castor was therefore in the required position at Jan. 2 d. 15 h. 45 m. 1·15 s., *i.e*, at 3 h. 45 m. 1·15 s. on the morning of the third of January.

To determine the Longitude of a Station by an Observed Altitude of a Known Star.—Three altitudes of the star are measured, and the means of the altitudes and of the times taken, as in the case of the sun; so that the observation to be calculated stands thus:—

Sept. 29 d. 15 h. 2 m. 3 s. G.M.T. d. alt. of Arcturus, was 41° 38′ 0″.

After the altitude has been corrected, the calculation is performed exactly as in the case of the sun, down to the determination of the hour-angle in time. From the hour-angle the local mean time is found as above explained, and the longitude is deduced by comparing it with the known Greenwich mean time of the observation.

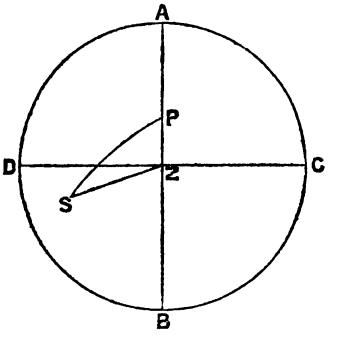
Or we may proceed thus:—Having determined the hour-angle in time, infer the local sidereal time of the observation. From the known Greenwich mean time of the observation infer the Greenwich sidereal time of the observation, as explained on p. 483 of the Nautical

Almanac; the longitude can then be found by comparing the local sidereal time with the Greenwich sidereal time.

Ex. Let the above-named observation be made with a sextant, whose index error was 6′ 25″ off, at a station in latitude 51° 20′ 20″ N, and whose approximate longitude is 8 h. W.; find its longitude exactly.

The usual figure is shown in the annexed diagram:—

Fig. 132.



Corrected altitude	20°	49′	45″
Latitude	51	20	20 N.
Declination (p. 347, N.A.).....	19	48	3 N.

Hence ZS = 69° 10′ 15″, PZ = 38° 39′ 40″, PS = 70° 11 57″ and therefore SPZ = 81° 5′ 14″, or 5 h. 24 m. 21 s.

We may then proceed as follows:—

Hour angle.....	5 h.	24 m.	21 s.	W.
Right ascension (p. 347, N.A.)	14	10	16	
Local sid. T.	19	34	37	
Sid. T. local mean noon	12	34	51	
Sidereal interval since mean noon.....	6 h.	59 m.	46 s.	
Local mean time (p. 484, N. A.) Sept. 29 d.	6 h.	58 m.	37 s.	
Greenwich mean time, Sept. 29 d.	15	2	3	
Longitude	8	3	26	W.

Or we may proceed thus:—

Greenwich mean time	15 h.	2 m.	3 s.
Interval in sid. units since M.N. (N.A., p. 482)..	15	4	31
Sid. T. of G.M.N. (p. II) Sept. 29.....	12	33	32
Greenwich sid. T.....	27	38	3
Or G. sid. T.....	3	38	3
Local sid. T. (as above)	19	34	37
Longitude	8	3	26 W

The Chronometer.—Hitherto we have spoken of the chronometer, as if it gave the exact Greenwich mean time directly. In point of fact

this is never the case, as a chronometer always has a certain small daily gain or loss. If it is in good order, the daily gain or loss is called the *rate* of the chronometer. When a chronometer is put into the hands of a traveller, he has with it a memorandum stating that on a certain day it was so much fast or slow, and had then a gaining or losing rate of so much per diem. It is evident that under these circumstances, if the rate continue constant, the observer knows the Greenwich mean time at any instant, thus:—Suppose the chronometer was 11 m. 17·8 s. slow at Greenwich mean noon, on April 3rd, and had a gaining rate of 4·1 s. per diem; if it read 7 h. 27 m. 31 s. on the morning of the 25th of April, the Greenwich mean time at the instant would be April 24 d. 19 h. 37 m. 19 s.; for it is now less slow by the gain of 4·1 s. per diem for 21 days and $\frac{42}{60}$ths of a day, or by 1m. 29·5 s., *i.e.*, it is now 9 m. 48·3 s. slow. This, however, depends on the rate continuing constant, and, as a chronometer is always liable to *error of rate*, the traveller whenever he is stationary for two or three days should determine the error of the chronometer at about the same time on successive days; the errors thus determined ought to differ from each other by the rate. If it is found that the rate has varied there will be an unknown error in all the longitudes determined by the chronometer; in fact the traveller has lost the Greenwich mean time, and, unless other sources of information are at hand, he can only recover it by means of lunar observations.

To Determine the Error of a Watch showing Local Mean Time.—This problem is the same as that of finding the longitude as above explained; except that the assistant notes the time from the watch, instead of from a chronometer showing Greenwich mean time. In all cases it is to be assumed that the longitude is known either exactly or approximately, and that the error of the watch is not great so that the Greenwich mean time is known approximately. Now (1) if we are to determine the local mean time from an observed altitude of the sun, we need the Greenwich mean time only for taking out the declination of the sun, and the equation of time from the Nautical Almanac, so that a small error in the Greenwich mean time will not sensibly affect the calculated local mean time. (2.) If we are to determine the local mean time from a measured altitude of a star, we need the longitude only for the determination of the sidereal time of local mean noon, and an error of 6 m., or 1° 30″ of longitude, would introduce an error of barely 1 s. into the calculated local mean time.

Ex. At a station in latitude 51° 20′ 20″ N., and in approximate longitude 3 m. 0 s. W., on September 19 d., 3 h. 8 m. 17 s. by the watch, the double altitude of sun's upper limb was 50° 49′ 30″, the index error of the instrument being 2′ 35″ on; find the error of the watch.

The principal steps of the calculation are as follows:—The assumed approximate Greenwich mean time is, September 19 d., 3 h. 11 m. 17 s., and the sides of the triangle SPZ are ZS = 64° 54′ 24″, SP = 88° 43′ 25″, PZ = 38° 39′ 40″.

Hence the hour angle is	49°	22′	11″ W.
The local apparent time	3 h.	17 m.	28 s.
The equation of time (to be subtracted)	0	6	24
The local mean time	3	11	4
The watch showed	3	8	17
Hence the watch is slow by	0	2	47

If the watch error had turned out to be large, the declination used in calculating the hour angle might have been considerably in error, and this in turn might have sensibly affected the hour angle. In such a case the local mean time found as above must be considered as an approximate result, and the operation must be repeated, using the calculated local mean time instead of the watch time, and now the error in the assumed Greenwich mean time being small, the calculated watch error will be sensibly correct. In such a case as that given in the example, there is nothing gained by repeating the calculation, for though the Greenwich mean time turns out to be more nearly September 19 d. 3 h. 14 m. 4 s. than September 19 d. 3 h. 11 m. 17 s., yet the declination taken out with the former date will differ from that taken out with the latter date by less than 3″.

Ex. At the same station as in the last example, at 7 h. 3 m. 24 s. p.m. by a watch on September 29th, the double altitude of Arcturus (which was to the west of the observer) was measured as 41° 38′ 0″ with a sextant, whose index error was 6′ 25″ off.; find the error of the watch.

The sides of the triangle SPZ are found to be—

ZS = 69° 10′ 15″, SP = 70° 11′ 57″, PZ = 38° 39′ 40″.
Hence hour angle = 81° 5′ 13″ or 5 h. 24 m. 20·8 s. west.

Right ascension (N. A. p. 347) ..	14	10	15·7
Local sidereal time	19	34	37
Local mean time	6	59	56
Watch time	7	3	24
Watch is fast by	0	3	28

N.B.—The watch error and longitude can also be found by an altitude of a planet, but account has to be taken of its proper motion.

SECTION XXVII.

DETERMINATION OF VARIATION OF COMPASS AND DIRECTION OF MERIDIAN.

The bearing of the magnetic north from true north, or, as it is called, the variation of the compass, can be found by observation of the sun. The principle of the determination is this:—The bearing of the sun from the magnetic north is observed with the compass; his bearing at the same instant from true north is obtained from calculation; a comparison of the two bearings will plainly give the position of the one north point relatively to the other. The calculation may be made to determine the sun's bearing—(1.) When he has a given observed altitude. (2.) When he is in the act of rising or setting.

To find the Bearing of Magnetic North from true North by an observed Altitude of the Sun.—The observation and calculation in this case closely resemble those used in the longitude problem above explained, so that we may treat the matter briefly. The observer takes the sextant and brings the two images of the sun together; the assistant takes the compass and keeps the sun's disc bisected by the wire of the line of sights. When the observer has an exact contact of the two images of the sun, he calls "stop" and reads the sextant, and the assistant reads the compass; the means of three such observations are taken as in the longitude problem, so that the data are such as those in the following example:—

Ex. At approximate Greenwich mean time Sept. 30 d. 21 h. 42 m., the double altitude of the sun's lower limb was 61° 17′ 40″ (the index error of the instrument being 8′ 40″ off), when the bearing of the sun's centre was 167° 45′ east of magnetic north; the observation was made in the morning at a station in latitude 51° 20′ 20″ N.; find the variation of the compass.

The steps of the calculation are as follows:—

(*a.*) Draw the "usual figure."

(*b.*) Determine the sides of the triangle PZS.

(*c.*) Calculate the angle PZS, which is called the azimuthal angle, by the formula—

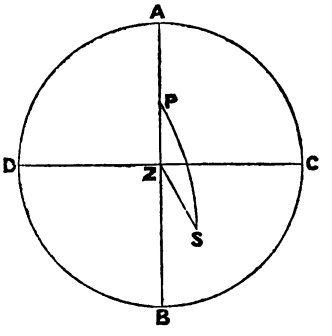
$$2 \log \text{Sin } \tfrac{1}{2}\text{PZS} = \log \text{Sin } (s-\text{PZ}) + \log \text{Sin } (s-\text{SZ}) + \text{ar. c. log PZ} + \text{ar. c. log SZ}.$$

(*d.*) Compare the angle PZS with the bearing from magnetic north. This is best done by making in the "usual figure" the angle AZH equal to the calculated value of PZS, and then making the angle HZN equal to the observed bearing from magnetic north (N), this angle, being measured back towards A, fixes the position of N relatively to A, and thus answers the question.

In the above example we have:—

(*a.*) The "usual figure."

FIG. 133.



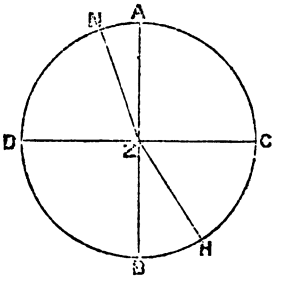
(*b.*) The sides of the triangle to the nearest ten seconds are—

$$PZ = 38° 39' 40'', ZS = 59° 2' 20'', PS = 93° 18' 40''.$$

(*c.*) Hence PZS equals 149° 4′.

(*d.*) Make the angle AZH (Fig. 134) equal to 149° 4′; and then measure back towards A the angle HZN equal to 167° 45′, and we see that the magnetic north (N) is 18° 41′ west of true north (A).

FIG. 134.



The observer might take the altitude of a known star, while the assistant observed its bearing from the magnetic north. The calculation would then be in all respects the same as in the case of the sun, except that there would be no occasion to note the Greenwich mean time of the observation, as the star's declination does not sensibly vary from day to day.

To find the Bearing of Magnetic North from true North by observing the Sun's bearing from Magnetic North when Rising or Setting.—In an open country we may take the sky-line to coincide with the rational horizon, at least for the purposes of the present problem. Now on the horizon the atmospheric refraction is about 32′, *i.e.*, it about equals the sun's apparent diameter. Consequently, when the sun's lower limb is seen to be about a semi-diameter above the sky-line, its centre is in the act of rising or setting. If at this instant its bearing from magnetic north or south be observed, we have the bearing at the instant the sun's zenith distance was 90°. Now an easy calculation will give us the sun's bearing from true north or south at the instant its zenith distance was 90°. A comparison of these two bearings will at once show the bearing of the magnetic north relatively to the true north.

The Greenwich time of the observation is of course known approximately, so that the sun's declination is known; also the latitude of the station is known. The bearing can then be calculated from the formula—

$$\text{Cos (lat.) Cos (bearing)} = \text{Sin (decl.)}$$

If the sun's declination is north, the calculated bearing is the bearing of the sun from the north point of the horizon; if the sun's declination is south, it is the bearing of the sun from the south point of the horizon. In other words, the declination and the point from which the bearing is reckoned are of the same name. If this rule is used, none of the angles that enter the question exceeds 90°. The bearing is (of course) east of north or south in the morning, and west of north or south in the evening.

Ex. In lat. 51° 20′ N., the sun was observed to rise, bearing 81° east of magnetic north, on the morning of Aug. 5th; the Greenwich mean time of the observation was 4 h. 20 m. A.M. Find the variation of the compass.

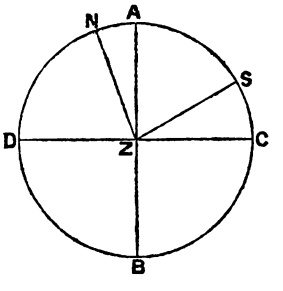
The G.M.T. of the observation is Aug. 4 d. 16 h. 20m., and therefore the declination is 16° 58′ N.

Log Sin 16° 58′	=	9·46511
Log Cos 51° 20′		9·79573
		9·66938

Therefore, the bearing is 62° 9′, *i.e.*, as the declination is north, the bearing of the sun is 62° 9′ east of true north, and consequently the magnetic north is 18° 51′ west of true north.

The comparison of the bearings of the sun from true and magnetic north can be effected, as was explained in the foregoing problem, by drawing a figure thus: the circle represents the horizon, A, B, C, D,

FIG. 135.



the north, south, east, and west points, Z being the zenith. Make the angle AZS equal the bearing of the sun from the true north (62° 9′). Make the angle SZN equal to its bearing from the magnetic north (81°); this gives the position of N, the magnetic north viz., 18° 51′ west of true north.

It may be observed (*a*) that in the calculation the quantities may be taken to the nearest minute; (*b*) that the time of sunrise or sunset may be taken from the table of semi-diurnal arcs in Chamber's tables, pp. 416, 417; (*c*) that the table of amplitudes, pp. 414, 415, might be used instead of the above calculation. (*d*) This method of determining the variation of the compass is not suitable in high latitudes.

The Direction of theMeridian at any station is, of course, known with considerable exactness when the variation of the compass is known. If the compass is held in such a manner that the reading equals the variation, so that the line of sight points to true north or south, two points taken in the direction of the line of sight will mark out the direction of the meridian. The instrument commonly employed for "laying down a north line," *i.e.*, for marking the direction of the meridian is a theodolite; it may be well, therefore, to say something more on the subject.

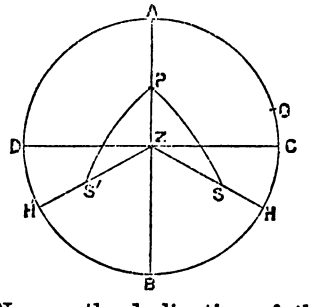
Determination of the Direction of the Meridian by equal altitudes.—Suppose that a heavenly body is at a given altitude before reaching the meridian, and that its bearing from the zero point of the horizontal limb of the instrument is read off; suppose that without changing the position of the instrument, the bearing of the heavenly body from the zero point is read off when it comes to an equal altitude after passing the meridian. If the declination of the heavenly body has continued constant during the interval, it is plain that the observations were made when it was at equal distances from, but on opposite sides of, the meridian, and consequently that the mean of the two readings is the bearing of the zero point of the instrument from true south (or north). It is plain that when the bearing of the zero point from true south (or north) is known the telescope can be set with its axis pointing due north or south. If a flag staff is then set up so as to be covered by the intersection of the wires in the focus of the object-glass of the telescope, it will be a north or south mark relatively to the centre of the instrument.

(1.) The above method can be applied to any bright fixed star, and very good results obtained, provided the telescope is furnished with proper means for lighting up the wires so as to render them visible by night.

(2.) If the observations are made on the sun, a correction will have to be made in consequence of his motion in declination between the two observations.

Let S and S′ be the positions of the sun at equal altitudes before and after noon, and let O show the direction of the zero point of the instrument. Then the first reading (R) is OH, and the second

FIG. 136.



reading (R′) is OH′. Now as the declination of the sun changes in the interval between the observations, the angle HZB is not exactly equal to the angle H′ZB; and the arc OB, which is the bearing of the zero point east of south, is given by the formula—

$$OB = \tfrac{1}{2}(R + R') + x,$$

where x is a number calculated from the formula—

$$x = \frac{\text{Change of dec. in } t}{2 \text{ Cos (lat.)} \times \text{Sin } (\frac{1}{2} 15\, t)'}$$

where t is the interval between the observations. The sign of x is negative when the change of declination is such as to bring the sun nearer the elevated pole in the interval. The reading is supposed to be taken in the direction east through south to west in the northern hemisphere, and east through north to west in the southern hemisphere. An error of a few minutes in t will not sensibly affect the value of x. The value of x rarely exceeds a few minutes of angle, and is very small near midsummer or midwinter, for then the sun's declination changes very slowly.

Ex. On 16th September, in latitude 51° 20′ N., the reading of the theodolite, when the sun had a certain altitude, was 47° 28′; after an interval of 6h. 58m., it was found to have an equal altitude, and then the reading of the theodolite was 170° 12′. What was the bearing of the zero point?

The change in the sun's declination per hour (N. A., p. I) is 58″, and is such as to increase its distance from the north pole; consequently x is positive. And we have

$$x = \frac{202''}{\text{Cos } 51° 20' \text{ Sin } 52° 15'}$$
$$= 409'' = 6' 49''$$

Hence the required bearing is $\frac{1}{2}(47° 28' + 170° 12') + 6' 49''$ or 108° 57′ east of south.

Determination of the Direction of the Meridian by the Pole Star.— (1.) When the pole star is at its greatest elongation, *i.e.*, its greatest distance east or west from the pole, it is seen to move in the field of view of the telescope along a line which is sensibly vertical for several minutes together. The bearing of it from the zero point when in either of these positions is therefore easily taken. If the observer takes the bearing when it is at one elongation, and afterwards when it is at the other elongation, half the sum of the two bearings will be the bearing of the zero point from true north.

(2.) If both these observations cannot be made, suppose that θ is the calculated value of the bearing of the pole star from the true north point at one of its greatest elongations, and suppose that A is the bearing of the star from the zero point at the same instant, then the bearing of the true north point from the zero of the instrument is $A \pm \theta$, the sign + or − being used according as the star and the zero point are on the same side or on opposite sides of the north point. Care must therefore be taken to ascertain whether the pole star is at east or west elongation when observed. The numerical value of θ can be calculated from the formula—

$$\text{Sin } \theta \text{ Sin } c = \text{Sin } d,$$

where c denotes the co-latitude of the station and d the north polar distance of the star; but as d is always a small angle, being about 1° 20′, and θ is a small angle except in very high latitudes, it is better to work with the above formula when put into the following shape—

$$\theta \text{ Sin } c = d + 0{\cdot}433'' \text{ Cotan}^2 c.$$

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It may also be observed that if the latitude is less than 50°, the second term of the right hand side of this equation can be omitted, and θ can be obtained from the formula—

$$\theta \text{ Sin } c = d,$$

with an error less than one second. In the last two formulæ d is to be taken in seconds, and then, of course, θ will be in seconds.

Ex. In latitude 51° 20′ 20″ the bearing of the zero point of the instrument was 85° 19′ 30″ west of the pole-star when at its greatest elongation on the evening of the 18th September, 1881. Find the bearing of the zero point from true north.

N.P.D. (N.A., p. 316) 1° 19′ 19·9″, or 4759·9″ log.	3·6775978
Co. lat. 38° 39′ 40″ ar. c. log Sin	0·2043196
$\theta = 7619{\cdot}3'' = 2°\ 6'\ 59{\cdot}3''$	3·8819174

The star was at its greatest elongation east, and therefore the bearing of the zero point was 83° 12′ 31″.

N.B.—In practical work an observation is always connected with previous work, and therefore an observer would never be in doubt whether the greatest elongation was east or west. But if he were in doubt he could reason in a way that will be best explained by considering the above example. The right ascension of the star is about 1h. 16m.; it is therefore at its greatest elongation west at (about) sidereal time 7h. 16m., and at its greatest elongation east at sidereal time 19h. 16m.; now, on the 18th September the sidereal time of mean moon was (about) 11h. 50m., and therefore the star was at its greatest elongation east at about half-past seven in the evening, and this must have been the elongation at which it was observed. It may also be observed that if the value of θ is calculated from either of the exact formulæ the value of θ comes out 2° 7′ 0·4″.

Any other circumpolar star can be used instead of the pole star, and its bearing from the north or south point of the horizon can be calculated by the formula—

$$\text{Sin } \theta \text{ Sin } c = \text{Sin } d.$$

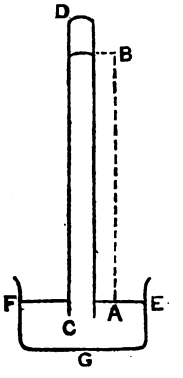
The other formulæ of the last article are applicable to the pole star only. The pole star has the peculiar advantage that owing to its nearness to the pole it remains sensibly at its greatest elongation for a much longer time than any other bright star in the neighbourhood of either north or south pole. However, a star with a polar distance of 20° would continue for about two minutes within 1″ of its greatest elongation to an observer in latitude 40°, and consequently such a star as α-Trianguli Australis could be advantageously used by an observer in South Africa or in Australia for determining the direction of the meridian. Similarly β-Ursæ Minoris or α-Ursæ Majoris, and several others might be used at stations north of the equator.

SECTION XXVIII.

DETERMINATION OF HEIGHTS BY THE BAROMETER.

The Barometer.—Let CD be a glass tube of uniform bore 34 or 35 inches long, closed at D and open at C; let it be filled with mercury and the open end stopped, say by the experimenter's thumb

FIG. 137.



let the tube be placed in a vertical position with the end C in a basin or cistern containing mercury EFG. If the end C is now opened by removing the thumb some of the mercury will flow out of the tube into the cistern, but a column of mercury about 30 inches high will remain in the tube, and above it a vacuum. The height of the barometric column is reckoned by the difference AB between the levels of the mercury in the tube and in the cistern, and its weight per square inch of section equals the pressure per square inch of the atmosphere on the surface EF of the mercury in the cistern. This is the principle of the mercurial barometer; but, practically speaking, the instrument is made in several forms, and the traveller ought to be well acquainted with the particular instrument that he carries with him. When the distance AB is said to be the height of the barometer the statement requires two or three qualifications. Thus, if the bore of the tube is less than three-quarters of an inch in diameter, the mercury is slightly depressed by the capillary action of the glass on the mercury; again, a scale is attached to the instrument to enable the observer to read the height of AB; the zero point is, of course, on the level of EF. Now if the pressure of the atmosphere varies mercury will fall out of the tube into the cistern, or will be forced out of the cistern into the tube; in the one case the level of EF will rise and in the other fall; the amount of the rise and fall will depend on the cross sections of cistern and tube. Corrections of the reading are thus required for capillarity and capacity. There may also be errors of graduation and an error in the position of the zero point. "Barometers intended for accurate observation are now usually exa-

mined at Kew Observatory before being sent out, and a table is furnished with each instrument showing its 'index error' at every half inch of the scale."*

When the height of the barometer has been thus correctly observed, it does not serve as a measure of atmospheric pressure such as can be compared with measures made under other circumstances, unless it has been corrected for temperature. The object of the correction is to determine the height of the barometer as it would have been if the temperature of the mercury had been 32° F. If this correction is to be made accurately a brass scale should be used as long as the tube of the barometer and correct at 32° F. Now if with this scale the reading is h when the temperature is t° F., the corrected height will be—

$$h - h \times 0{\cdot}00009(t - 32),$$

i.e., we must subtract from the measured height the nine one hundred thousandth part of the height for each degree Fahrenheit that its temperature is above freezing. It is not unusual to subtract the one-ten thousandth part of the height for each degree that the temperature of the mercury is above freezing. This, however, is the correction for the temperature of the mercury only without reference to the scale. In what follows we shall suppose that the height of the barometer has in all cases been reduced to what it would have been at a temperature of 32° F. The temperature of the mercury is ascertained by a thermometer attached to the barometer.

Determination of Heights by the Barometer.—Let P and Q be two stations, and let the vertical height of Q above P be denoted by Z. A formula, called the barometric formula, is to be found in several books; this formula enables us to calculate the value of Z from the observed heights of the barometer and temperatures of the air at P and Q. For our present purpose it will be enough to say that the formula in question can be written thus:—

$$Z = HAB + C,$$

where H, A, B, and C are four numbers that must be calculated separately. When this has been done the value of Z can be found with very considerable accuracy by multiplying the first three together and adding the fourth to the product. Of course the multiplication can be facilitated by the use of logarithms.

(1.) The value of H in feet is given by the formula—

$$H = 60{,}380 (\log h - \log k),$$

where h and k are the corrected readings of the barometer at P and Q respectively. H is the approximate height of Q above P, *i.e.*, the calculated height as it would be if the temperature of the air were 32°F., and the force of gravity constant and of the same value as in latitude 45°.

(2.) The value of A is given by the formula—

$$A = 1 + 0{\cdot}002036 (t - 32),$$

where t denotes the mean temperature of the air in degrees Fahrenheit, *i.e.*, half the sum of the temperatures of the air at P and Q. This factor is the correction for the temperature of the air. The temperature of the air at the upper and lower strtion must be ascertained by a thermometer detached from the barometer.

(3.) The value of B is given by the formula—

$$B = 1 + 0{\cdot}00256 \text{ Cos } 2\lambda,$$

* Everett's "Deschanel's Natural Philosophy," p. 157, 6th ed.

where λ denotes the latitude of the station. In calculating B it must be remembered that Cos 2λ is negative when λ is greater than 45°. This factor is the correction for the variation with the latitude of the force of gravity at the sea level.

(4.) Besides varying with the latitude gravity also varies with the height above the sea level; the correction due to this variation is denoted by C. If the lower station is not much above the sea level, and if n is the nearest number of thousand feet in the approximate altitude, we can find C from the formula—

$$C = \frac{n(n + 52)}{21}.$$

But if the lower station is considerably above the sea level, and if the heights of P and Q above the sea level to the nearest thousand feet are m and n respectively, then the value of C in feet is given by the formula—

$$C = \frac{n(n + 52)}{21} - \frac{m(m + 52)}{21}.$$

Thus if the height of P above the sea level were 3750 feet, and the approximate height of Q above P were 4580 feet, the values of m and n are respectively 4 and 8, and consequently—

$$C = \frac{8 \times 60}{21} - \frac{4 \times 56}{21} = 12 \text{ feet.}$$

But if P had been only a few hundred feet above the sea level the value of n would be 5, and consequently—

$$C = \frac{5 \times 57}{21} = 14 \text{ feet.}$$

The values of A, B, and C can be taken from special tables, which are printed on pp. 216, 217.

Ex. In latitude 51° 30′ N. the barometer after reduction read 25·55 in. at the upper station, and 29·81 at the lower; the temperature of the air at the upper station was 50·5° and at the lower 63°. What was the height of the upper station above the lower?

(1.) Calculate H—

Log 29·81	1·4743620
,, 25·55	1·4073909
	0·0669711

Hence H = 60380 × 0·0669711

(2.) The mean temperature of the air being 56·75° the first table gives—

A = 1·0504.

(3.) The latitude being 51° 30′ the second table gives—

B = 0·99944.

Hence HAB = 60380 × 0·0669711 × 1·0504 × 0·99944 = 4245·1 feet.

(4.) Assuming that the lower station is not more than two or three hundred feet above the sea the third table gives—

C = 11·5,

and therefore the height of the upper station above the lower is—

$$4245{\cdot}1 + 11{\cdot}5 = 4257 \text{ feet.}$$

Remarks.—The following points regarding the barometric formula are worthy of attention:—*First.* An accurate result can only be looked for when the traveller has a good instrument and uses it carefully. For instance, if the readings of the barometer are 20 inches and 25 inches, and an error of a tenth of an inch has been made in each case, the error in the calculated height may be as much as a twenty-fifth part of the whole. *Secondly.* There is no room for serious error in the corrections B and C, and the corrections themselves are comparatively small. *Thirdly.* The correction for temperature of the air is of great importance, in extreme cases it may amount to as much as a tenth part of the calculated height. An error of one degree of Fahrenheit's scale in the mean temperature of the air will produce an error of as much as one five hundredth part of the calculated height. Unfortunately the temperature of the air is known only at the two stations, so that an incurable uncertainty exists as to the exact value of the mean temperature; the best that can be done under ordinary circumstances is to assume that the mean temperature equals half the sum of the temperatures at the upper and lower station respectively. *Fourthly.* No account has been taken of the effect of any moisture that may exist in the atmosphere. *Fifthly.* In regard to the constants that enter the barometric formula, the only one that calls for remark is the number 60,380, which is sometimes given as 60,200, 60,158, &c. These variations depend on the particular experimental determinations of the weights of air and mercury from which they are deduced. It is believed that the number 60,380 represents, for latitude 45°, the results of the best experiments.

Approximate Formulæ.—When an observer has a table of logarithms, and the three subsidiary tables printed in this volume, the calculation of the height of the one station above the other is so easy that there is little to be gained by omitting any part of it. However the following modifications of the barometric formula may be noted—

(1.) The formula for the approximate height is sometimes given thus:—

$$\text{H (in fathoms)} = 10{,}000\ (\log h - \log k).$$

If the example on page 213 were worked by this formula we should at once get H = 669·7 fathoms, and then correcting for temperature of air we should get—

$$Z = 669{\cdot}7 \times 1{\cdot}0504 = 703{\cdot}5 \text{ fathoms} = 4221 \text{ feet.}$$

(2.) A well-known transformation of the expression $\log h - \log k$, gives the following result:—

$$H = 52{,}500\ (h - k) \div (h + k).$$

If h and k were 30 in. and 28 in. respectively, the error would not exceed the two thousandth part of the calculated value of H, so that for heights up to 2000 feet, the formula could be used without sensible error. Nor is the error great for heights considerably above 2000 feet.* If the example on page 213 were worked by this formula and corrected for temperature of air, the result would be—

* The formula—

$$H = 52500\ \frac{h-k}{h+k}\left\{1 + \frac{1}{3}\cdot\left(\frac{h-k}{h+k}\right)^2\right\}$$

$$z = 52{,}500 \times 4{\cdot}26 \times 1{\cdot}0504 \div 55{\cdot}36 = 4243{\cdot}5 \text{ feet.}$$

(3.) It is plain from the last formula that for points not much above the sea level the differences of elevation are at the rate of about 91 feet for each tenth of an inch in the difference of the barometric readings, or the required height in feet may be found by multiplying the difference of the readings by ten thousand and dividing the product by eleven. Thus, if the readings were 29·87 in. and 29·365 in., the difference of elevation is $0{\cdot}405 \times 10000 \div 11 = 368$ feet.

The aneroid barometer is a secondary instrument that can be used as a substitute for a mercurial barometer. It is more portable, and indicates changes of atmospheric pressure more quickly than a mercurial barometer.

It is made in several forms; the traveller should, therefore, make himself well acquainted with the particular instrument that he carries with him. In principle it is a flat cylindrical box, from which nearly all the air has been withdrawn. The top of the box is elastic, and yields to the pressure of the external air, the extent to which it yields being greater or less according as the pressure is greater or less. The movements of the top due to variations of atmospheric pressure are small but are made evident by means of a pointer (like the hand of an ordinary weather glass), the position of which on a properly constructed scale shows the atmospheric pressure at any instant. The scale is graduated by comparison with a standard barometer. The instrument is compensated for temperature, and it is possible for the maker to effect this compensation with a considerable degree of nicety. A thoroughly good aneroid should give readings identical with those of a mercurial barometer reduced to 32° F.; but it ought not to be assumed without careful comparison that any given instrument is good. If on several successive days, during which the temperature has varied considerably, the aneroid is compared two or three times a day with the reduced readings of a mercurial barometer, and it is found that the difference between the readings of the two instruments is constant, it will follow that the aneroid has been properly compensated; the constant difference is of the nature of an index error, and means are provided for adjusting it. Besides this preliminary testing, the aneroid ought from time to time to be compared with a standard barometer to make sure that its indications are still correct; for, like a watch, it is liable to go wrong. For successive observations an aneroid should be kept in one position, *e.g.*, suspended vertically for each observation.

The readings of the aneroid can be used for the determination of heights in just the same way as those of the mercurial barometer, but there is no preliminary reduction of the readings to 32° F., for that is already done by the compensation of the instrument for temperature.

Ex. In latitude 47° at the lower of two stations, whose height above the sea level was 2100 feet, an aneroid barometer read 27·93 inches, and thermometer 63·4° F.; at the upper the aneroid barometer read 24·87 inches, and the thermometer 51·7° F.; what was the height of the upper station above the lower?

Here as in the foregoing example, p. 213—

could be used up to 10,000 feet without producing an error of more than 2 or 3 feet at the most.

$$H = 60380 \times 0{\cdot}0503951$$
$$A = 1{\cdot}0520$$
$$B = 0{\cdot}99982$$
$$\text{Therefore } HAB = 3201$$
$$\text{and } C = 13{\cdot}7 - 5{\cdot}2 = 9$$

Required height.... 3210 feet.

Remark.—Several aneroids by good makers were tested at Kew under the supervision of Professor Balfour Stewart. The results arrived at were as follows:—

(1.) If an aneroid, correct to begin with, is used for a balloon or mountain ascent, it will continue to give fairly correct readings up to a decrease of about 6 inches of pressure. But its range of correctness can be considerably increased by previous comparisons with a standard barometer, the results of which are registered in a tabular form.

(2.) If an aneroid is kept for some time at the top of a mountain, and is correct to start with, it will give good results in the descent up to an increase of about 8 inches of pressure.

(3.) After being subject to sudden changes of pressure, the position of the zero of an aneroid gradually changes.

(4.) A good aneroid of large size may be corrected for temperature by an optician, so that the residual correction may be very small.

(5.) Under any of the above circumstances, a large aneroid is more likely to give accurate indications than a small one.*

FIRST TABLE.—*Values of A.*

Mean temp.	Factor.	Mean temp.	Factor.	Mean temp.	Factor.
10°	0·9552	35°	1·0061	60°	1·0570
11	0·9572	36	1·0081	61	1·0590
12	0·9593	37	1·0102	62	1·0611
13	0·9613	38	1·0122	63	1·0631
14	0·9633	39	1·0143	64	1·0652
15	0·9654	40	1·0163	65	1·0672
16	0·9674	41	1·0183	66	1·0692
17	0·9694	42	1·0204	67	1·0713
18	0·9715	43	1·0224	68	1·0733
19	0·9735	44	1·0244	69	1·0753
20	0·9756	45	1·0265	70	1·0773
21	0·9776	46	1·0285	71	1·0794
22	0·9796	47	1·0306	72	1·0814
23	0·9817	48	1·0326	73	1·0835
24	0·9837	49	1·0346	74	1·0855
25	0·9857	50	1·0367	75	1·0876
26	0·9878	51	1·0387	76	1·0896
27	0·9898	52	1·0407	77	1·0916
28	0·9919	53	1·0428	78	1·0937
29	0·9939	54	1·0448	79	1·0957
30	0·9959	55	1·0468	80	1·0977
31	0·9980	56	1·0489	81	1·0998
32	1·0000	57	1·0509	82	1·1018
33	1·0020	58	1·0529	83	1·1038
34	1·0041	59	1·0550	84	1·1059

* "Proceedings of the Royal Society," vol. 16, p. 480, A.D. 1868. The experiments were "executed in a very careful manner by Mr. T. W. Baker."

N.B. If the thermometers are read to tenths of a degree, add 2 for every tenth of a degree to the fourth decimal place in the factor, *e.g.*, if the mean temperature of the air is 51·7° F., the value of A is 1·0387 + 0·0014 = 1·0401.

SECOND TABLE.—*Values of B.*

Lat.	Factor.	Lat.	Factor.	Lat.	Factor.
0°	1·00256	30°	1·00128	60°	0·99872
5	1·00252	35	1·00087	65	0·99835
10	1·00240	40	1·00044	70	0·99804
15	1·00222	45	1·00000	75	9·99778
20	1·00196	50	0·99956	80	0·99760
25	1·00165	55	0·99913	85	0·99748

N.B. In using this table interpolate for intermediate latitudes in the usual way, observing that the factor decreases as the latitude increases, *e.g.*, if the latitude is 13° 10′, the difference is $18 \times \frac{3° \ 10'}{5°} = 11$, and the required factor is 1·00240 − 00011 = 1·00229.

THIRD TABLE.—*Values of C.*

Height in feet.	Correction to be added.	Height in feet.	Correction to be added.	Height in feet.	Correction to be added.
1,000	2·5	11,000	33·3	21,000	73·7
2,000	5·2	12,000	36·9	22,000	78·2
3,000	7·9	13,000	40·6	23,000	82·9
4,000	10·8	14,000	44·4	24,000	87·6
5,000	13·7	15,000	48·3	25,000	92·5
6,000	16·7	16,000	52·3	26,000	97·4
7,000	19·9	17,000	56·4	27,000	102·5
8,000	23·1	18,000	60·6	28,000	107·6
9,000	26·4	19,000	64·8	29,000	112·8
10,000	29·8	20,000	69·2	30,000	118·1

N.B. In the above table the height is that of the upper station above the lower, on the supposition that the lower is not much above the sea level. But if the lower is considerably above the sea level, the corrections must be taken out for the height of each station above the sea level, and then the value of C is the difference of the two corrections. Thus, if P were only a few hundred feet above the sea level, and the approximate height of Q above P were found to be 4580, we should say, height 5000, and therefore

C = 13·7 feet.

But if P were 3750 above the sea level, we should have the heights of P and Q above the sea level 4000 and 8000, so that the two corrections are 10·8 and 23·1, and therefore

C = 23·1 − 10·8 = 12·3.

These results agree with those obtained by calculation on p. 213.

Description of the Barometrical Instruments.

It has been shown that the height of the column of mercury in an ordinary barometer requires correction for "capacity" when used as an indication of altitude. In the instruments constructed for measuring altitudes, known as "mountain barometers," there are means of measuring the actual height of the top of the column above the surface of the mercury in the cistern, and thereby of obviating the necessity for this correction. In these instruments the correction for "capillarity" (previously mentioned) is avoided by lowering the zero point of the scale of inches marked on the barometer the same quantity as that of the capillary depression.

The barometer devised by M. Fortin is that most commonly used in these operations. The lower part of the cistern is a leathern bag, A, Fig. 138, compressed by a screw, B. To prepare the barometer for carriage, compress the mercury until it rises to within less than a quarter of an inch of the top of the tube, so that it may not have room enough to strike the glass a heavy blow if jerked, but may have sufficient space to expand with any increase of temperature. The instrument should be carried about with the cistern upwards, as a precaution against the introduction of air or the escape of mercury.

When preparing to take an observation, the barometer is slowly turned right end upwards, and suspended from a tripod stand, in a vertical position, as shown in Fig. 139. The screw is then lowered until the surface of the mercury in the cistern falls to the level of the point of an ivory peg, P, Fig. 138, which is fastened in the cover of the cistern; this is the case when the extremity of the point is seen to touch its image in the mercury. The upper part of the cistern is of glass, so that the surface of the mercury and the ivory point are visible.

This point is the zero of the scale of inches engraved on the metal case which contains the tube. Thus the true height is measured free of "capacity" error, capillarity being compensated for as explained above. It is therefore only necessary to apply to the reading the corrections for temperature of the mercury (p. 212) and of the air. The "attached thermometer," *t*, Fig. 139, which is fixed in contact with the tube, shows the temperature of the mercury. The temperature of the air is shown by a detached thermometer.

It is important that the top of the mercurial column should be always of the same form. The "meniscus" (*μηνίσκος*, a crescent) should be decidedly rounded; if it appears flat the barometer should be tapped, or the mercury lowered and again raised by the cistern screw.

The observer's eye being exactly at the same level as the top of the column, and the tube being so placed that there may be a bright light behind it, the vernier V, Fig. 138, should be moved until its lower edge forms an exact tangent to the meniscus. This edge is the zero of the vernier, which is usually divided to read 0·002, or $\frac{1}{500}$th of an inch. The barometer should not be exposed to artificial heat, or sunshine or rain when taking observations.

The perfectness of the vacuum above the column should be tested occasionally, as the presence of any air would entirely vitiate observations. The cistern screw being turned so as to lower the column an inch or two, the barometer is inclined gently, and the mercury allowed to strike the top of the tube, when the sound should be a sharp tap; if

FIG. 138.

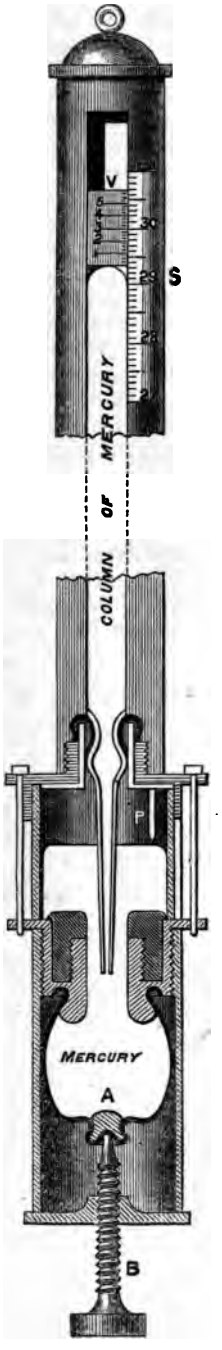
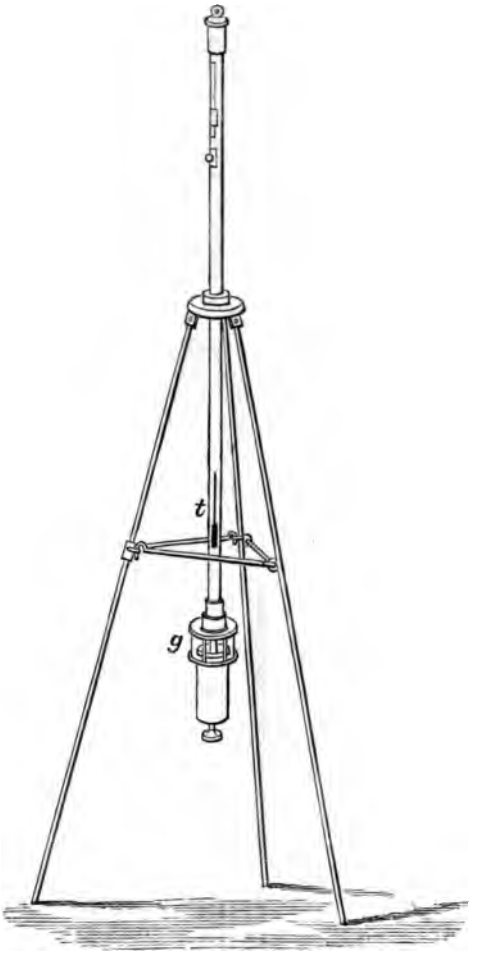


FIG. 139.



muffled or dead the presence of air is recognised. To expel it, the barometer should be turned cistern upwards, and the latter gently tapped; by this means the air will be forced to ascend and escape. This operation must be performed with great care, so as not to fracture the tube.

The junction of the tube to the cistern is usually effected by a packing of chamois leather, which is sufficient to retain the mercury, but porous enough to transmit the variations of air pressure.

In some barometers, instead of arranging for measuring the height of the column in such a manner that there may be no correction for capacity, the correction is applied to the observed reading, thus: The maker marks a certain point in the scale of inches as the "neutral point" NP, being the height at which the column is found by comparison with a standard barometer to be correct, as read by the scale of inches. He also marks the proportion between the internal diameters of the tube and of the cistern thus, $\frac{1}{40}$. It is evident that when the mercury stands higher than the NP, the correction for capacity must be added, when below the NP deducted from the reading. Thus, if the capacity be $\frac{1}{40}$, the NP at 29·8 inches and the mercury stand at 30·5, the correction will be $(30{\cdot}5-29{\cdot}8)\ \frac{1}{40} = 0{\cdot}017$, which, added to the observed reading, makes the correct height 30·517 inches.

In some barometers the whole scale is moveable, and its zero capable of adjustment to the level of the mercury in the cistern, thereby obviating the necessity for correction for capacity. In others it is avoided by making the divisions on the scale less than true inches above the neutral point, and greater than true inches below it.

FIG. 140.

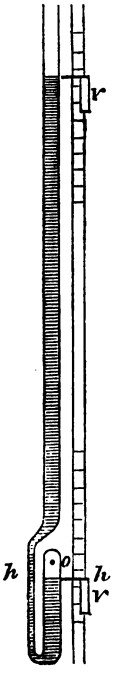
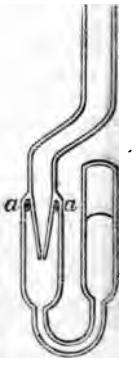


FIG. 141.



The Syphon barometer devised by Gay-Lussac is frequently used in determining altitudes. It consists of two glass tubes of similar calibre, set one above the other in the same vertical line (Fig. 140), and connected by a capillary tube bent as represented. The object of this tube is to prevent the entrance of any air into the upper part when the instrument is being carried about, as by reason of its very small calibre it always remains charged with mercury.

The ends of both tubes are closed, but there is a fine puncture at *o* for the transmission of air pressure; this puncture is generally closed with a substance sufficient to prevent the escape of mercury.

The instrument is reversed for carriage. Some patterns are provided with an air trap, Fig. 141. Should any air find its way into the tube past the capillary joint, it is caught at *aa* and prevented from ascending to the vacuum.

The height of the barometric column is measured by means of a fixed or of a moveable scale. If moveable, its zero is adjusted to correspond exactly with the horizontal *hh*, Fig. 140, and the height of the column is read by a vernier, which moves along the scale. If fixed, it is provided with two verniers—one to read the height of the lower, the other of the upper meniscus; the difference between these numbers shows the height of the column if the zero of the scale is below the lower meniscus. The sum of the numbers if the zero is intermediate.

No correction for capacity is required with this barometer, as the mercury rises as much in one tube as it falls in the other. The effect of capillarity is also generally neglected, but care must be taken to bring the meniscus in each tube to a similar form by tapping the instrument, as the end of the column that is falling will be less convex than that which is rising.

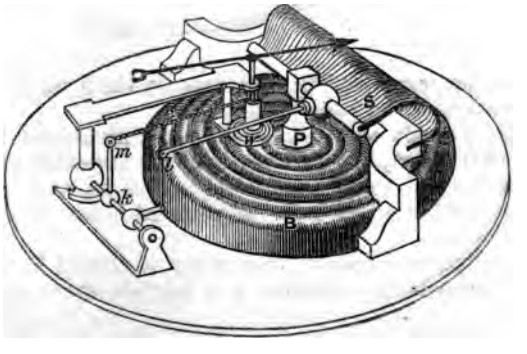
The Aneroid Barometer.

The mechanism of this instrument is shown, Fig. 142, with the dial removed. Its principle has been explained, page 215.

On account of its portability and strength, the aneroid will as a rule be used by military men in preference to the mercurial barometer.

B is the flat cylindrical box nearly exhausted of air; its surface is of very thin metal, corrugated in order to render it more sensitive

Fig. 142.



to changes of pressure. This box would tend to collapse were it not supported by a spring S, to which it is connected by a pillar P. As the atmospheric pressure varies, the rise or fall of the surface of the box is communicated by the levers *l* and *m* to the pointer.

C is a fine chain, passing round the pivot which carries the pointer; and a hair spring *w*, connecting the pivot and chain, keeps the latter in tension.

Thus, suppose the atmospheric pressure to decrease, the surface of the box would rise, carrying with it P and the lever *l*. This movement revolves the shaft *k*, and moves the lever *m* outwards, winding the chain off the pivot, tightening the hair spring, and turning the pointer to the left.

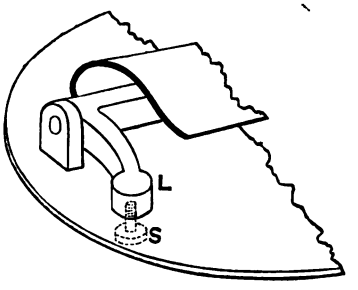
The compensation for temperature mentioned is effected by composing the lever *l* of two slips of brass and steel soldered together. The rate of expansion of these metals being unequal has the effect of causing the lever to bend instead of lengthening or shortening directly. If this has been properly effected the pointer should indicate the same pressure inside and outside a room where there is a difference of temperature of 30° or 40°, and no difference of level. The instrument should be kept for a quarter of an hour or so in each place, so as to acquire the same temperature as the surrounding air.

The compensation is also effected by leaving a small quantity of air or introducing a little gas into the vacuum box; the expansion and contraction of this gas partly counteracts that of the metal of the instrument at different temperatures.

The correction for air temperature (detached thermometer) must, of course, be applied as when using the mercurial barometer.

At the back of the aneroid is a screw for the correction of the instrument, and the adjustment of its readings to correspond with those of a mercurial barometer, a correction which, as has been said, it is necessary to apply to the aneroid barometer from time to time.

FIG. 143.



The adjusting screw S, Fig. 143, acts on the lever L, and thereby affects the tension of the main spring.

Mountain aneroids are now sometimes constructed to read altitudes up to 15,000 feet, but ordinary aneroids (weather glasses) being only graduated down to 27 inches—equal on an average to an altitude of about 3,800 feet—require adjustment before they can be used in high mountains.

Before reading the aneroid barometer it should be swung backwards and forwards to overcome any friction there may be in the mechanism.

Some aneroids have besides the usual scale of inches, the corresponding altitudes marked on the dial, the level of the sea being assumed as reaching 29·5 inches, but this arrangement would be of little use for the determination of heights, which is of course indicated not by one reading of the barometer, but by the difference of two readings taken at the top and bottom of the mountain within a short time of each other, or by comparison between simultaneous readings of two barometers. A more useful arrangement is that in which a scale of heights constructed according to the table, p. 67, at a temperature of 50°, is engraved on a moveable arc capable of being set to any zero at the time of commencing the day's observations.

The temperature of boiling water under varying atmospheric pressures at different altitudes was, before the invention of the aneroid, much used as an indication of relative heights, when it was desirable to employ a more portable and convenient instrument than the mercurial barometer; but as the aneroid, as now constructed, is, in nearly all respects, superior to the thermometer for the purpose, it has generally taken its place as part of a traveller's equipment.

APPENDIX.

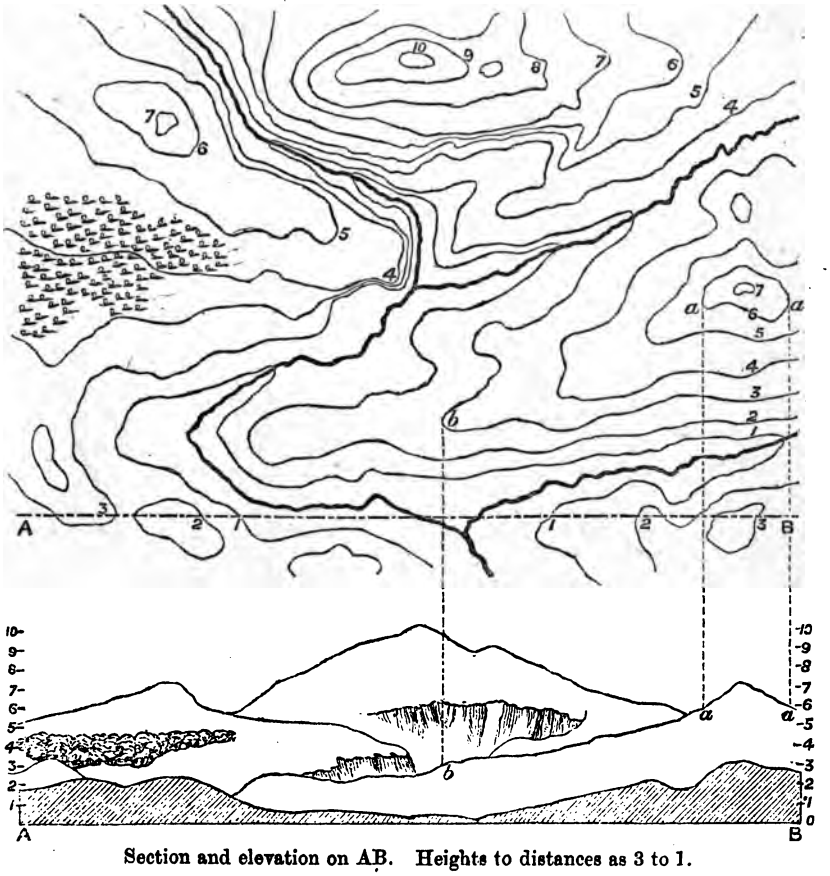
ELEVATIONS.

The "elevation" of an object is its projection on a vertical plane. As regards contour plans, it is a representation of such a view of the ground as would be obtained if the observer's eye were always at the same level as the spot observed, and looking at it in a direction always perpendicular to a given line on the plan.

Let AB be the vertical plane. The section occupies the foreground; parts of the ground which are higher than this section will appear

Fig. 144.

Scale 6 inches to a mile. 30 feet contours.



Section and elevation on AB. Heights to distances as 3 to 1.

behind and above it; all ground of the same height as, or lower than it will be hidden.

The outline of the hills nearest the front will be first drawn, their forms may be determined as shown by drawing lines *a*, *b*, &c., perpendicular to AB, and tangential to the contours, connecting them with the planes to which they belong in the elevation.

Any details, such as cliffs, woods, houses, &c., which would be visible, may also be shown in their proper positions in the elevation.

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